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Natural Regeneration of Loblolly Pine

in the South Atlantic Coastal Plain

Production Research Report No. 13

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Southeastern Forest Experiment Station
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By Karl F. Wenger and Kenneth B. Trousdell [1]

INTRODUCTION

A long growing season, ample rainfall, gentle topography, and favorable soils make the southeastern United States one of the important timber-producing regions of the world. Loblolly pine (*Pinus taeda* L.), ranging from southern New Jersey to central Florida and west to eastern Texas and southern Arkansas, is the principal commercial species over most of the region. It grows best on sandy loams and heavier soils with plentiful moisture. These conditions are common in southeastern Virginia and northeastern North Carolina, and in the Coastal Plain of South Carolina. In the Coastal Plain of North Carolina, longleaf pine (*Pinus palustris* Mill.) was originally the characteristic tree (*2*).[2] Repeated cycles of lumbering, land clearing, and abandonment favored loblolly pine to the extent that it largely displaced longleaf on the heavier soils and is now generally distributed throughout eastern North Carolina.

Soils and climate are also exceptionally favorable to loblolly pine in northern Louisiana and southern Arkansas. It does not grow in the Mississippi Delta. In the lower Coastal Plain of the Gulf Coast States and Georgia and in Florida, longleaf pine and slash pine (*Pinus elliottii* Engelm.) are more prominent. Loblolly pine is scarce in the sandhills of North and South Carolina, where longleaf is again common; and in the peat lands of eastern North Carolina it gives way to pond pine (*Pinus serotina* Michx.).

With these exceptions, loblolly pine largely dominates the timber economy of the southern pine region. In the South Atlantic States [3] it is the principal raw material for a thriving and growing forest products industry. Plants manufacturing forest products in that territory are more numerous than any other kind (*23, 24, 48*), and the value of their products is exceeded only by that of textiles and tobacco. They provide jobs for well over 100,000 people (*23, 24,*

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[1] Southeastern Forest Experiment Station, Forest Service. Special credit is due G. M. Jemison and I. H. Sims, formerly of the Southeastern Forest Experiment Station, for initiating the program which has yielded much of the information summarized and presented in this publication. The Camp Manufacturing Co., Inc., Franklin, Va., contributed substantially to this research, making land available and conducting various forestry operations required in the experimental work. The Southern Johns-Manville Products Corp., Jarratt, Va., and the Chesapeake Corp. of Virginia, West Point, Va., also gave material help in several individual studies.

[2] Italic numbers in parentheses refer to Literature Cited, p. 73.

[3] Virginia, North Carolina, and South Carolina.

48), and a substantial additional number is engaged in supplying these plants with wood.

With the exception of furniture manufacturing, which is concentrated in central North Carolina, much of the forest products industry of the South Atlantic States is located in the Coastal Plain. Only about one-fourth of the sawmills are found there, but these account for nearly one-half the lumber production (*92*). Sixteen plants, with a 24-hour capacity of 8,270 tons, comprise the pulp and paper industry in the region. Ten of these, with a capacity of 6,070 tons, operate in the Coastal Plain. In 1954, the three States produced 4.1 million cords of pulpwood, of which 2.0 million, or 48 percent, came from the Coastal Plain (*82*). Of these volumes of lumber and pulpwood, 80 to 90 percent was softwoods (*82, 92*). The rapidly growing population and rising national income will very likely increase the demand for forest products in the years to come, so these industries will probably continue to grow.

The extent to which the Coastal Plain industries are dependent on loblolly pine can be judged from the acreage and volume in the species. Of the 21.3 million acres of forest land in the Coastal Plain, 50 to 60 percent is occupied by softwood forest types. In addition to loblolly pine, these include longleaf pine, pond pine, shortleaf pine (*Pinus echinata* Mill.), Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.), and cypress (*Taxodium distichum* (L.) Rich.), but loblolly pine occupies two-thirds of the softwood type area. With respect to wood volume, loblolly pine is even more impressive, accounting for approximately 84 percent of the total softwood volume in the Coastal Plain of the South Atlantic States.

To supply the forest products industries with wood and to satisfy local and farm needs, 5 to 7 percent of the forest area is cut in some way every year.[4] In the pine types the percentage is probably higher. Much of the cutting takes only scattered trees so that reproduction is not needed, and some cutting is in areas unsuitable for pine. Probably about one-half of the forest land that is harvested annually should be in loblolly pine. New stands must be established on the harvested acreage if the needs of the growing industry are to be continuously satisfied. However, the area in hardwood types is increasing throughout the Southeast, while the area of the much more productive pine types is decreasing (*61, 62*). Pine is not, therefore, becoming reestablished on much of the harvested acreage.

Both planting and natural seeding will be needed to reverse the trend toward hardwoods. Hardwood stands on pine sites can be converted to pine only by planting, and planting may often be necessary in pine areas in poor seed years. But because of the extensive acreage, the limited supplies of planting stock, and the higher cost of forest planting, planting can be only a partial solution to the problem of perpetuating and increasing the pine acreage in the territory. Thus, the reestablishment of pine on much of the harvested acreage will require the use of natural seeding.

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[4] Cruikshank, J. W., and McCormack, J. F. Forest Survey data on file at the Southeast. Forest Expt. Sta., Asheville, N. C.

Considerable research on the natural regeneration of loblolly pine has been carried on in recent years. The fruiting characteristics of this species were studied in some detail in southeastern Virginia from 1946 until 1951 (*75*, *101*, *103*). Seeding periodicity and seed dispersal were recorded on the Duke Forest[5] over a period of 13 years from 1936 to 1948 (*40*, *56*, *76*). Investigations of methods of hardwood control, including use of fire, have been conducted since 1946 on the Santee Experimental Forest[6] (*11*, *12*, *14*).

The Bigwoods Experimental Forest[7] in northeastern North Carolina provided an exceptional opportunity to test earlier findings on a large scale and to investigate in more detail the factors that influence natural regeneration. The forest consists of 1,365 acres, which bore, at the time of its establishment in 1946, a remarkably uniform, mature stand of loblolly pine. Since that time scattered seed tree, seed strip, and selection cuttings have been made in 35-acre compartments in combination with different methods of seedbed preparation and hardwood control.

Annual observations of seed production confirmed earlier findings in the Duke Forest. Records of seedling establishment and seed production served as a basis in determining seed and seedbed requirements for the natural regeneration of loblolly pine (*74*, *85*). The extensive areas of natural reproduction provided ample opportunity to observe the behavior and growth of loblolly pine seedlings and the development of hardwood competition (*104*, *105*). Comparisons of seedling stocking revealed the effect of the different methods of seedbed preparation and hardwood control on the establishment and survival of reproduction. Repeated inventories produced valuable information concerning the rate and causes of mortality of seed trees (*91*).

This information is widely applicable in the South Atlantic Coastal Plain and probably beyond. The soils of the Bigwoods vary from poorly drained silt loams with heavy, plastic subsoils to deep, well-drained loamy sands and occur in sufficiently large areas so that most of the 35-acre compartments lie entirely within bodies of similar soils. The same or similar soils occupy 60 percent of the Coatal Plain of North Carolina[8] and 63 percent of the Coastal Plain of Virginia.[9] A similar percentage probably occupies the Coastal Plain of South Carolina. Although some are poorly drained, these are all upland soils. Thus, the information to be presented does not apply to swamps, bays, bogs, "pocosins," or to any areas of organic soils. It also does not apply to the sandhills of North and South Carolina or to other areas of excessively drained, coarse sands.

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[5] Property of Duke University, in Durham County, N. C.

[6] Maintained by the U.S. Forest Service in Berkeley County, S. C.

[7] Maintained in Hertford County, N. C., by the U.S. Forest Service in cooperation with the Camp Manufacturing Co., Inc., Franklin, Va.

[8] Lee, W. D. An approximate correlation of soils in the Bigwoods Experimental Forest with soils of the 30-county area of the Tidewater Forest Research Center (*North Carolina*). Official correspondence on file at Tidewater Forest Research Center, Franklin, Va.

[9] The soils in the Bigwoods Experimental Forest were correlated with soils in eastern Virginia by the senior author according to the method used by W. D. Lee, soil scientist of the North Carolina Agricultural Experiment Station, who made the North Carolina correlation.

ECOLOGICAL BEHAVIOR OF LOBLOLLY PINE

Consistent success in natural regeneration of loblolly pine requires a familiarity with the ecological behavior of the species: its place in the undisturbed secondary plant succession, the characteristics that determine its behavior, and the changes in the plant succession when it is disrupted.

Secondary Plant Succession

Most of the pure stands of loblolly pine now found in the South Atlantic Coastal Plain became established on abandoned cropland or on severely burned areas (*2, 70, 98*). These stands are ecologically transient and without further disturbance would inevitably be displaced by the climax oak-hickory association (*2, 70, 98*).

Pine is normally the first aboreal dominant in old fields. The supply of seed is likely to be more plentiful than that of other species, and old-field conditions are nearly ideal for germination and initial establishment (*7*). Fields turned out of cultivation are immediately invaded by herbaceous plants that shortly give way to grasses, mainly *Andropogon* spp. (*70*). The establishment of pine is not related to the herbaceous succession, however, and usually occurs in one or sometimes two waves during the first few years after abandonment when the seed supply is adequate and the weather favorable. Occasionally pine establishment may be delayed beyond the third year by insufficient seed or unfavorable weather (*68*).

Light-seeded, or intolerant, hardwoods seldom become established as early as pine in old fields, apparently because they are not so well adapted to old-field conditions. Sweetgum (*Liquidambar styraciflua* L.) is one of the most abundant of these, but it requires more plentiful and more stable moisture for germination and is less drought resistant than loblolly pine in the first year (*7*). Consequently, repeated cycles of clearing and reforestation have favored loblolly pine, so that pine seed is usually much more plentiful than sweetgum seed near old fields. Differences in seed-bearing age, in amount of seed produced, and in the manner and distance of seed dispersal also favor pine. Thus, hardwoods usually follow pine in old-field succession, and early invaders of old fields are sweetgum, red maple (*Acer rubrum* L.), yellow-poplar (*Liriodendron tulipifera* L.), blackgum (*Nyssa sylvatica* Marsh.), and minor species such as waxmyrtle (*Myrica cerifera* L.). These increase in numbers and size in the understory up to middle age of the pine stands (*70*).

Components of the oak-hickory climax appear as seedlings usually when the pine stand is 20 to 30 years old, although they frequently appear earlier (*70*). The number, proportion, and size of the oaks and hickories in the understory increase throughout the life of the pine stand (*5*). The number of pine seedlings remains constant at a low level, showing that a few pine seedlings are regularly established but die without having any effect on the succession toward the hardwood climax. The oaks and hickories together with secondary hardwoods far outnumber pine seedlings

under all overstory densities on all sites after the stand reaches 20 to 30 years of age.

The number of pine stems is constantly reduced throughout the life of the stand, rapidly in early years but more slowly later. Mortality is caused mainly by competition, but other agencies, such as insects, lightning, and wind, are also important, particularly at more advanced stand ages. At younger ages, openings made in the dominant canopy by the death of single trees are closed by expansion of crowns of survivors. When the trees become so large that crown expansion no longer closes such openings, the hardwoods in the understory become dominant. This process begins at 75 to 100 years of age and continues until the pine is entirely eliminated between 200 and 300 years of age (fig. 1).

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FIGURE 1.—A 150-year-old stand of loblolly pine.

The rate of succession toward the hardwood climax varies with site quality. Oosting (*70*) found that a 34-year-old pine stand on bottom land was at the same stage of succession as a 75-year-old pine stand on upland. Coile (*22*) reported that sweetgum and dogwood (*Cornus florida* L.) occupied greater areas in the understory of pine stands on good sites than on poor sites at all ages. He found no relation between site quality and the stocking of

several species of oak. Ferrell (*28*) found that sweetgum and red oak (*Quercus falcata* Michx.) seedlings grew faster on lighter soils but could detect no influence of soils on the growth of white oak (*Q. alba* L.) and dogwood seedlings.

Progress toward the oak-hickory climax is a direct consequence of the difference between pine and hardwoods in their requirements for germination, survival, and growth. The forest floor and the light and moisture conditions under the pine stand increasingly favor hardwoods as the stand grows older. Forest litter prevents contact of the pine seed with mineral soil, which is essential for good germination (*74*). On the other hand, hardwood leaf litter is the best seedbed for heavy-seeded species, such as oaks (*3*, *43*).

Light intensity increasingly favors hardwoods as the stand grows older and a hardwood understory develops. Photosynthesis in loblolly pine develops in proportion to light intensity and reaches its maximum rate only under full sunlight; yet in yellow-poplar, red maple, white oak, northern red oak (*Quercus rubra* L.), and dogwood, photosynthesis attains a maximum rate at one-third, or less, of full sunlight (*44*, *46*). The maximum rate is greater in oak than in pine (*44*). Photosynthesis is also influenced by soil moisture: with decreasing soil moisture the photosynthetic rate of loblolly pine is reduced more rapidly than that of the associated hardwoods (*7*, *44*). Hardwoods thus are distinctly superior to pine in photosynthesis under all conditions of light and soil moisture.

Hardwoods also have a decided advantage over loblolly pine in their root development. Dogwood seedlings 6 months old grown in the absence of competition had three times as many roots as loblolly pine seedlings of the same age (*45*). Coile (*21*) found that the primary root in 1-year-old, forest-grown white oak seedlings averaged more than four times as long as the primary root of similar loblolly pine seedlings. Lateral roots were eight times as long in white oak as in loblolly pine. The average weight of the root system of white oak seedlings was 100 times greater than that of loblolly pine seedlings. Oak and hickory seedlings develop a 10- to 15-inch taproot and yellow-poplar produces a deep, branchy root system in the first year (*84*).

Not only are root systems larger in hardwoods than in pine, but they are also larger in relation to tops. Kozlowski (*44*) found that, on a dry weight basis, the root system of 1-year-old oak seedlings was about twice as large for a given size of top as that of 1-year-old pine seedlings. Coile (*21*) found significantly more root growth per unit of shoot growth in oak seedlings than in pine. Wenger (*99*) found a much greater dry weight of roots in relation to tops in sweetgum seedlings than in pine seedlings in their second year over a wide range of soil texture and moisture availability.

In addition, the inherent superiority of hardwood root systems is enhanced by the low light intensity prevailing in forest stands. Kozlowski (*44*) found that 3-year-old oak seedlings grown in artificial shade were as large as seedlings grown in full light, but pine seedlings grown in the shade were smaller in all respects. The

roots of the shaded pine seedlings were much smaller in relation to the tops than the roots of the seedlings grown in full sunlight.

These differences between pine and hardwood seedlings mean that hardwoods are much better adapted to establishment and survival under a forest canopy. The weight of small roots in the upper 4.5 inches of soil was found to be the same in a mature shortleaf pine stand as in an uneven-aged hardwood stand on different soil (*20*). After fully stocked stands reach a certain age, the number and weight of small roots apparently become constant at the maximum level the particular soil will support under existing climatic conditions. This trend undoubtedly is an important factor in excluding subclimax species whose superficial root systems cannot compete with the established climax species for moisture and nutrients. Billings (*6*) pointed out that the deep root systems of hardwood seedlings in their first year would grow beyond the zone of greatest root competition in pine stands.

The relation of these characteristics of pine and hardwoods to their survival and growth in forest stands was studied by Kramer, Oosting, and Korstian (*47*). They found that the survival of loblolly pine seedlings was as good at the stand margin as in the adjacent field, although available soil moisture at the stand margin was as low as within the stand. Dogwood survival was best at the stand margin and somewhat poorer but equal within the stand and in the open.

In sharp contrast to loblolly pine, white oak survival was best within the stand, poorest in the open, intermediate at the stand margin, and better at all three locations than that of all other species. All species grew larger in the open than at the margin or interior of the stand. The difference was greatest in pine but was still evident in white oak. Loblolly pine seedlings in the shade apparently do not develop root systems large enough to compete with the existing vegetation. With ample light, however, their root systems become larger and supply the water and nutrients needed for survival and growth even under root competition equal to that within a stand (*72*).

Effects of Cutting and Fire

An acquaintance with the uninterrupted secondary plant succession can do no more than serve as a foundation for further knowledge because loblolly pine stands must be cut for economic reasons long before the climax is reached. Consequently, familiarity with the effects of cutting on plant succession is a necessary basis for planning regeneration measures.

In terms of pine and hardwood the composition of the stand that develops after cutting depends on how much of the dominant pine stand remains, how much of the hardwood understory is destroyed and mineral soil exposed, and on how many pine seed reach a favorable seedbed in the first year or two after cutting. The understory, including the roots, is often completely destroyed in skidroads and loading areas. Mineral soil is exposed, no sprouting occurs, and pine readily becomes established if seed is available.

In areas of less activity, the aerial part of the understory may be removed but the roots remain. Although the litter is disturbed and exposure of mineral soil provides a favorable seedbed for pine, the hardwoods sprout. Composition of the stand then depends on the comparative densities and growth rates of pine seedlings and hardwood sprouts and will vary. Undisturbed hardwoods usually preclude the establishment of a pine stand (*18*); the litter remains intact in undisturbed thickets, and the few pine seedlings that do become established undergo severe and usually fatal competition for light, moisture, and nutrients. Even where a favorable seedbed does occur under large hardwood trees, these trees not only deprive pine seedlings beneath their crowns of sufficient light, moisture, and nutrients, but also present a mechanical barrier to their height growth.

Such conditions occur in parcels of different sizes from a few square feet to substantial proportions of an acre, completely intermingled in the cutover areas. Until the comparatively recent introduction of tractor logging, logging methods did not favor pine reproduction. Horses or mules and high-wheeled carts destroyed few hardwoods and disturbed the soil surface very little. Thus, these older operations hastened the succession toward the hardwood climax, and the rapidity of change depended on how much of the dominant pine stand was cut (*70, 95*). Pine stems were removed by cutting sooner than they would have been by natural causes, leaving the hardwoods largely undisturbed and in a dominant position. However, the tractors used in most present-day logging in the Southeast break and uproot many hardwoods and in turning and pulling break up the litter and root mat over substantial areas.

Loblolly pine stands are also often burned, accidentally or purposely. To prescribe fire properly or to cope with the effect of accidental fires also requires a knowledge of the influence of fire on plant succession.

The effect of fire on the succession depends on the age of the pine stand and on the intensity, frequency, and season of burning. Loblolly pine stands become fairly resistant to surface fires at about 10 years of age (*19*). Usually, fire completely destroys younger stands, but older stands are damaged very little by surface fires.

Crown fires at any season of the year completely destroy the pine stand. Usually, fires of this type occur during periods of exceptionally high fire hazard, so that understory vegetation is also killed back to the ground. Since a burned soil surface is an excellent seedbed for loblolly pine (*74*), the proportion of pine in the stand developing after a crown fire probably depends on the supply of pine seed in the first year or two after the fire (*89*). Pine becomes established readily in the burned area, and the resulting stand is made up of pine seedlings and hardwood seedlings and sprouts. Oosting (*71*) found pine reproduction equal to hardwoods in basal area but not in number of stems 9 years after a crown fire, showing that the pine stems were growing much faster than the hardwoods and would probably form the bulk of the dominant stand.

Surface fires during the dormant season in older pine stands have very little effect on succession. Litter is consumed and small stems are killed (*51*). The hardwood stems are quickly replaced by sprouting, and the thin litter permits establishment of pine seedlings so that conditions quickly become as they were before, except that hardwood stems are probably more numerous (*5*, *50*, *51*, *71*).

Fires during the growing season may be very destructive because initial vegetation temperatures are higher, growing tissues are more exposed to heat, and sprouting is less vigorous than that following dormant season fires. Depending on how much of the overstory is killed, conditions after a summer fire range from something resembling those after a crown fire to a reduction in the smaller understory hardwoods only. The succession varies accordingly.

Fires within the first year after logging differ in their effects, depending on the time of the year they occur in relation to pine seedfall. During the dormant season they destroy not only advance reproduction but also whatever seed is present. Hardwoods are highly favored because a whole growing season must pass before another crop of pine seed is produced. Meanwhile, hardwood sprouts and herbaceous vegetation produce a new mantle of litter that retards pine germination.

On the other hand, fires before seedfall may favor pine establishment if they do not occur too early in the growing season. Hardwood stems killed after early August sprout very little until the following spring (*100*). Consequently, fires in late summer before seedfall not only increase favorable seedbed conditions by consuming slash and undisturbed litter, but also give pine seedlings an even start with hardwood sprouts and seedlings in the following spring (*17*). The earlier that fires occur in the summer, the more nearly the sprout and seedbed conditions approach those following dormant-season fires after logging.

Repeated fires at intervals of less than 10 years eventually eliminate loblolly pine (*19*, *98*). The process becomes relatively rapid when the dominant pine stand is clear cut or otherwise destroyed. Frequent fires then repeatedly destroy the pine reproduction, while hardwood stems are multiplied by seedling establishment, sprouting, and suckering (*30*). Continued frequent burning may ultimately result in a vegetational type dominated by grasses (*98*).

SEED PRODUCTION OF LOBLOLLY PINE

How Loblolly Pine Seed Develop

In common with the seeds of other hard pines, those of loblolly require nearly three growing seasons to mature from the time of flower bud initiation. Flower buds are formed during midsummer, probably from some time in June to the end of July. During the following spring, flowering occurs. Cones mature and seeds are cast during the second autumn after flowering.

In northeastern North Carolina staminate flower buds can be distinguished during October as small knobs around the base of

the buds. Sometime later, pistillate flower buds become evident as pointed swellings near the apex of the buds. Staminate flowers usually are the most plentiful and are borne all over the crown, while pistillate flowers tend to be concentrated in the upper parts of the crown. Growth increases rapidly in late winter, and for a short time before flowering the staminate buds are very noticeable. The staminate flowers are long, yellow catkins; the pistillate flowers are small, pink or red conelike structures borne upright on short stalks (fig. 2).

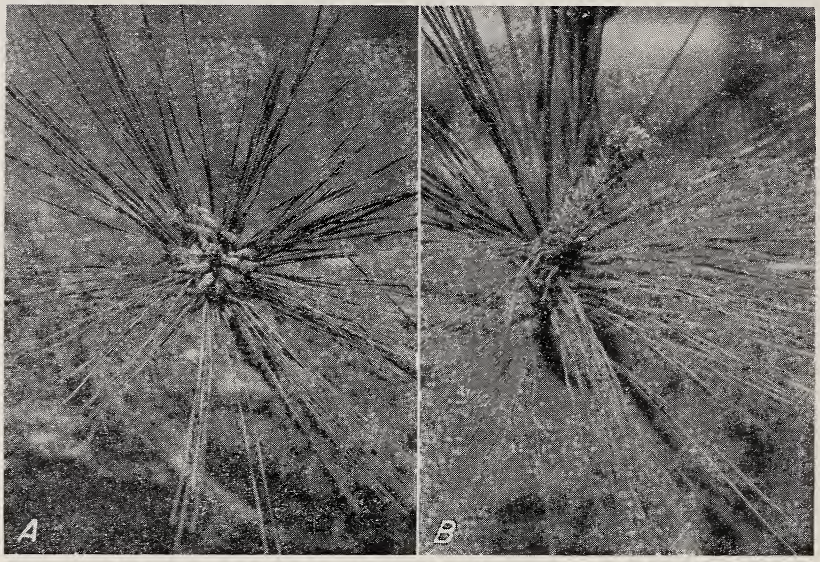

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FIGURE 2.—Loblolly pine flowers: *A*, Staminate or male flowers ready to cast pollen; *B*, female strobili ready to receive pollen.

Available information about the pollination, fertilization, and seed development of southern pines has been summarized by Dorman.[10] The pistillate flowers are always upright regardless of the position of the branch on which they grow. Paired ovaries lie on the upper surface of each cone bract. The ovaries open downward and toward the axis of the cone. During the flowering period, wind-borne pollen settles around the opening. Sometime later the ovules become mature and secrete a fluid, usually at night. The fluid fills the opening of the ovule from within to the rim or edge and as far beyond as surface tension allows. In doing so, this fluid comes in contact with some of the pollen grains lying in the opening. Being buoyant, the pollen grains float upward in the fluid, into the ovule, and come to rest against the tissue at the base of the opening. As the grains are rising in the opening, the fluid begins to be reabsorbed. Within 10 minutes reabsorption is com-

[10] Dorman, K. W. The genetics of southern pines. Southeast. Forest Expt. Sta., 52 pp. 1950. [Processed.]

plete, and the tissue against which the pollen grains rest is relatively dry. The opening closes after pollination is complete.

The pollen grains germinate promptly, but fertilization does not occur until late the following spring. The pollen tubes grow slowly toward the embryo sac, where they fertilize mature egg cells 14 months after pollination. At that time the cones are ½ to ¾ inch long, greenish brown, with very prominent spines on the ends of the still-inconspicuous scales. Growth of cones and seed is rapid during the second season, after fertilization takes place.

The ovule usually contains several mature egg cells, all of which may be fertilized by individual pollen grains. Normally, one embryo gains supremacy in development and finally absorbs any others. Occasionally 2 may grow to maturity and the seed produces 2 seedlings, 1 usually smaller and less vigorous than the other. Rarely does a seed contain three embryos.

Periodicity of Seed Production

Yearly Variation

The general or regional level of cone and seed production of loblolly pine varies considerably from year to year. This variation has been observed many times, and forest tree nurseries have taken it into account in planning seed collection (*97*). The general level of cone production also tends to be lower in the inland parts of the loblolly range than in the coastal areas (*96*).

Seed production of individual stands also varies from year to year, and such variation was observed in two mature, undisturbed stands in the Bigwoods Experimental Forest from 1947 to 1954 (figs. 3 and 4). The 1947 season was considered a "bumper" seed year, but 1948 and 1949 were very poor. Seed production of a 70-year-old, undisturbed stand in the North Carolina Piedmont varied less over the 8-year period from 1936 to 1943 (*76*) than that of the two Bigwoods stands. In an exceptionally good year, such as 1947, nearly all trees capable of seed production bear cones. In moderate years cone production is likely to be spotty, some stands producing good, and others poor crops. But cone crops may be fair in some stands even in the poorest years.

Along with the yearly variation in seed production goes a similar variation in seed quality. Pomeroy and Korstian (*76*) found a direct, positive relation between the size of the seed crop and the percentage of seeds that were sound (fig. 5). Seed crops of a 95-year-old and a 145-year-old stand in the Bigwoods Experimental Forest showed the same trend during the 7 years from 1947 to 1953.

Reasons for the yearly variation in seed production are not well understood (*86*, *97*). The number of flower buds formed varies from year to year for reasons that have not yet been determined. Flowers may be destroyed by subfreezing temperatures. Rain may disrupt or prevent pollination. To the extent that loblolly pine cross-pollinates, pollination may be inhibited because neighboring trees shed pollen at different times or because they are too far apart. Fertilization may not occur even though pollination is adequate. Drought may retard development at any time during the reproduction cycle. And insects damage both cones and seeds.

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FIGURE 3.—The type of seed trap used in estimating seedfall in loblolly pine stands.

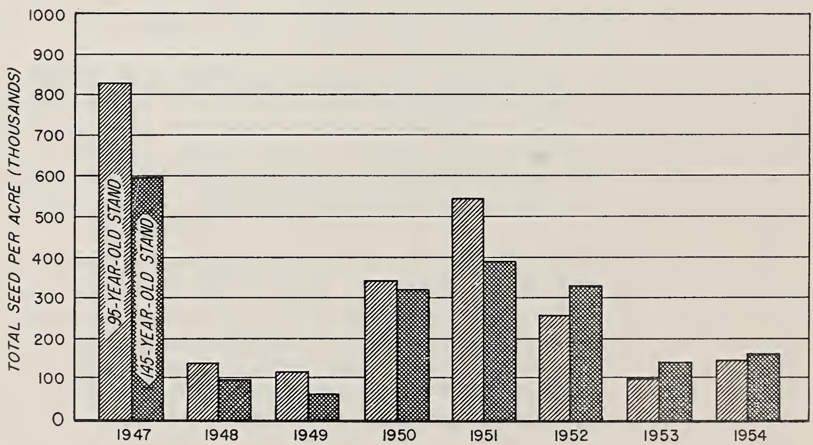

FIGURE 4.—The annual variation in seed production of two stands in the Bigwoods Experimental Forest, estimated by seed trapping.

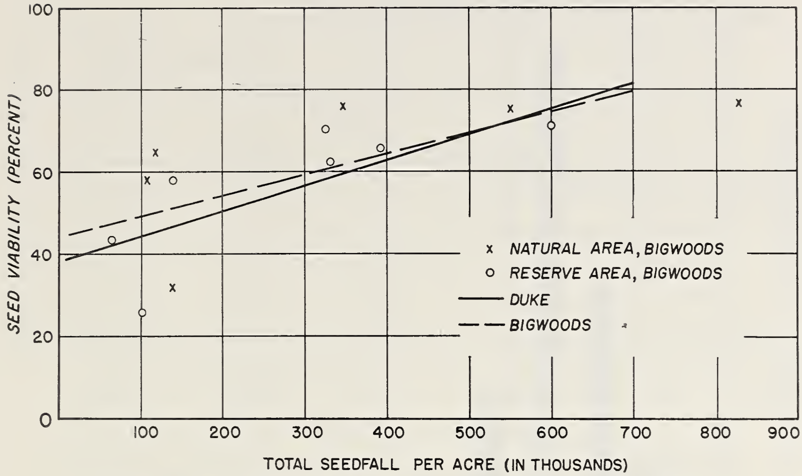

FIGURE 5.—Relation of seed viability to size of seed crop. (After Pomeroy and Korstian.)

In eastern Virginia and North Carolina most of the damage to developing cones is caused by a small moth *Dioryctria amatella* (Hulst.) (*42*). The larvae feed on all tissues inside the growing cones, partially or completely destroying them. This insect can also cause serious damage to flowers, seeds, and new growth. Cone damage from year to year apparently is not related to the general level of cone production. In 1949, 29 percent of the cones on a stand in southeastern Virginia were defective. In 1951, 30 percent were defective, although this was a very good seed year, and the stand produced many more cones than in 1949. The cone crop was moderately good in 1950 but 45 percent of the cones were defective. Another small moth, *Laspeyresia toreuta* (Grote), destroys individual seeds without otherwise damaging the cones (*42*). The larvae move from seed to seed along the stem of the cone. In 1949 this insect destroyed 2 percent of the seeds in two stands in southeastern Virginia. A loss of that size is of little importance in natural regeneration. Other insects undoubtedly are also responsible for cone and seed losses, but no data indicative of their importance are available.

Seasonal Variation

In northeastern North Carolina, seedfall usually begins some time in October, reaches a peak very quickly in late October or early November, and then declines. By January 1, 80 to 90 percent of the seed has fallen, although some continues to fall until late in the spring (fig. 6). This pattern of seedfall agrees closely with that observed in the Duke Forest near Durham, N. C. (*40*), and in the Santee Experimental Forest, S. C.

Peaks and troughs in the course of seedfall are caused by the weather. In the Duke Forest, dry, warm, windy weather increased seedfall, and cool, wet weather retarded it (*40*). The weather probably also affected the initial opening of the cones.

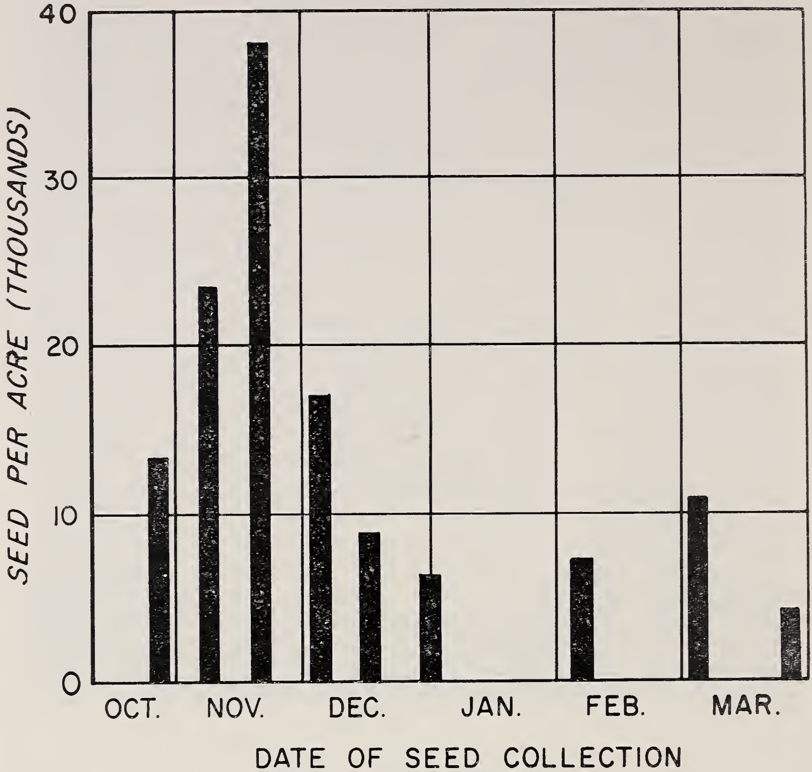

FIGURE 6.—The seasonal trend of seedfall as observed in the Bigwoods Experimental Forest, 1946.

In the same study, the viability of seed varied with the time the seed fell (*40*). The seed that fell during the first 8 weeks was 50 to 60 percent viable. Seed falling later was progressively lower in viability until the 18th week, when the viability levelled off at about 35 percent. Seed catches in coastal North Carolina showed a similar trend in viability (fig. 7).

Predicting Seed Crops

The approximate level of cone production of loblolly pine stands in a given locality can be estimated well before cone maturity because the cones are on the trees for two growing seasons. To get an estimate of the prospective crop, the cones can be counted at any time. However, estimates made more than 1 year before maturity are likely to be much in error. Many conelets are lost during the first growing season, mainly because of insect attack. During the dormant season and second growing season, losses are lighter.

Predictions made a year in advance require counts of first-year conelets, which are too small to be counted accurately from the ground, even with binoculars. Consequently, counts must be made where logging is in progress, which destroys the predicted crop.

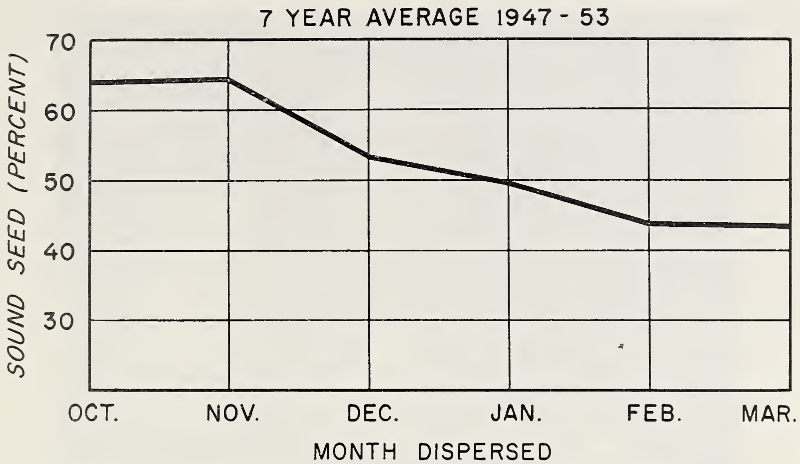

FIGURE 7.—Variation in seed viability during the period of seedfall.

However, experience has shown that such samples yield satisfactory predictions of the general level of the cone crop in the locality (*86*). After second-year cones reach appreciable size, they can be counted with acceptable accuracy in standing trees by using binoculars (*102*).

The forecasting method worked out by Trousdell (*86*) is based on the assumption that the forecaster knows the size of the preceding crop. The top 3 feet of the main stem are used to get the number of cones of both the old and the new crop (fig. 8). A number of sample trees give an average for the stand. The number of conelets in the new crop is then reduced 45 percent and expressed as a multiple of the old crop.

Relation of Seed Production to Tree Characteristics

Age

Although cones may occasionally be seen on loblolly pines less than 10 years old, appreciable numbers are not produced until the trees are much older. In general, tree species do not come into full seed production until the period of great vegetative vigor and rapid height growth in early life has passed (*93*). Thus, dominant and codominant trees in undisturbed, even-aged loblolly pine stands generally start producing seed in appreciable quantities at 30 to 50 years of age. Individual trees may start producing considerably earlier or later.

Advancing age, on the other hand, apparently has no detrimental effect on seed production. In the Bigwoods Experimental Forest, a 145-year-old stand produced as many seed as a 95-year-old stand over a period of 7 years. Consequently, loblolly pine can be depended upon to retain its seed-producing ability to the greatest rotation age that is feasible under management.

Similarly, quality of seed is unaffected by age of tree. The viability of seed from very young trees just beginning to bear is as high as that of seed from older trees (*97*). Also, the quality of

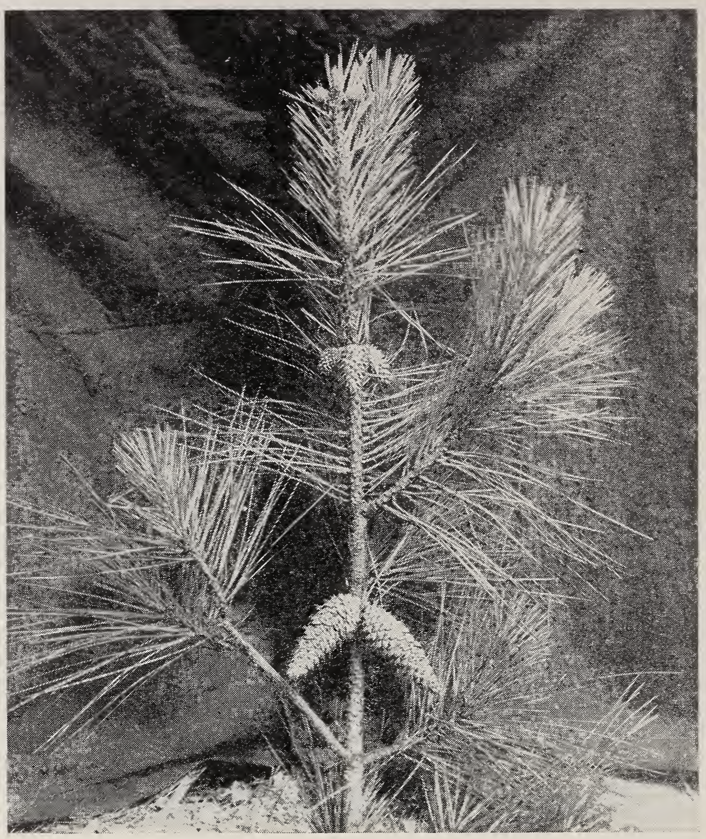

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FIGURE 8.—Three crops of loblolly pine cones as they appear in May.

seed from the 145-year-old stand mentioned above was as good as that from the younger stand. With respect to cones, however, an association has been found between the percentage of cones destroyed by insects and the age of the stand (*42*). On the average, cone losses tend to be higher in older stands.

Size

In stands that have come into full production, cone crops vary with tree size. The total number of cones is more closely related to the diameter at breast height than to any other dimension of the tree. Other characteristics, such as total height, crown length, crown ratio, crown density, and crown area are not consistent indicators of fruitfulness (*35*, *75*), probably because they cannot be measured so accurately as diameter.

In general, trees less than about 12 inches in diameter at breast height do not produce enough seed for stand regeneration (*75*). On trees above that size, cone crops are proportional to diameter (*103*). In good seed years 12-inch trees may bear fairly heavy

crops, but in poor seed years even the largest trees may produce relatively few cones.

Past Fruitfulness

Some trees consistently produce relatively heavy crops, some consistently produce light crops, and some are relatively variable, suggesting that fruiting capacity is to some extent hereditary (*26*, *75*). In southeastern Virginia, the cone production of scattered seed trees was closely related to diameter at breast height during two 3-year periods, 1931–33 and 1946–48 (*75*). However, the number of cones produced in 1946–48 was not related to d.b.h. in 1931–33 unless the production in 1931–33 was also taken into account. Data on cone crops of loblolly pine in southeastern Arkansas showed that current crops were more closely related to past production than to diameter (*35*).

An intensive study in southeastern Virginia (*103*) revealed that a significantly greater part of the variation in cone crops of dominant and codominant trees in 1949, 1950, and 1951 was accounted for by their past cone production (average of crops from 1946 through 1948) than by their diameter. The trees produced cones more nearly in accordance with their inherent fruiting ability when favorable rather than unfavorable conditions existed. As cyclic factors improved (poor to good regional crops from 1949 to 1951), the trees became more distinctly segregated by fruiting ability.

Little doubt remains, therefore, that of the several expressions of tree size, appearance, and behavior studied in relation to cone and seed production, past fruitfulness is the best indicator of future fruitfulness. This conclusion does not minimize the importance of diameter in this connection, however. Diameter is related to crown size, and large cone crops can be produced only if the inherently fruitful tree has ample crown surface for cone bearing.

The size of the cone crop on individual trees also has some influence on the percentage of cones infested by insects. Knight[11] found an indication that the percentage of infested cones was smaller in large crops than in small crops. The relation was definitely established with individual seed trees in southeastern Virginia.[12] In addition, the percentage of defective cones in the current year was directly related to the percentage defective in the previous year (fig. 9).

Relation of Seed Production to Environment and Treatment

Site Quality

The influence of site quality on cone and seed production has not been determined for loblolly pine, but it is generally accepted that trees growing in fertile soils of good physical characteristics bear larger cone crops than trees in poor soils (*93*). Knight (*42*) found that site quality also influenced cone losses. He found a

[11] Knight, F. B. Preliminary pine cone insect surveys in the Southeast. Unpublished report on file at the Southeastern Forest Expt. Sta.

[12] Wenger, K. F. Seed tree development study. Unpublished report on file at the Southeastern Forest Expt. Sta.

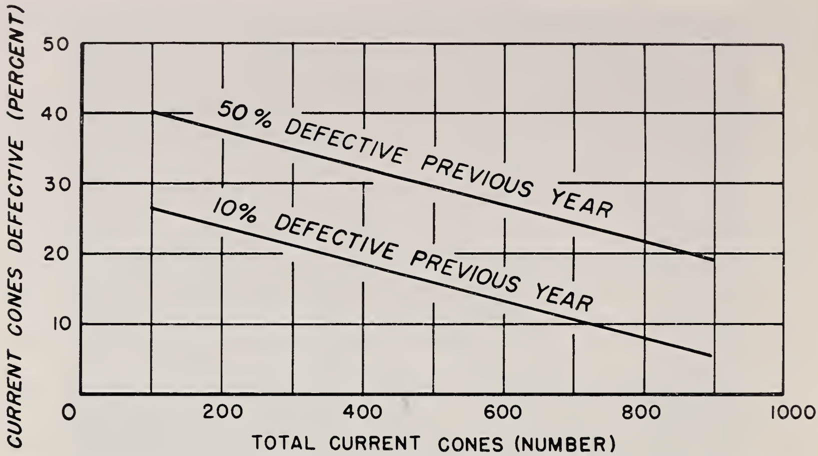

FIGURE 9.—The percentage of cones defective in relation to the total number of cones per tree and the percentage defective in the preceding year.

larger percentage of cones destroyed by insects on the better than on the poorer sites. He thought that the difference might be related to the cone production in poor seed years. On better sites some cones are present even in the poorest seed years. The insect population might thus be maintained at a higher level than on poor sites, where cones are virtually absent in poor seed years, although the insects (*Dioryctria* spp.) chiefly responsible for cone losses also feed on foliage and new growth.

Response To Release

A marked increase in cone production has frequently been observed several years after trees were released from competition by cutting (*4*, *17*). Until recently this increase was attributed to the expansion of crown and roots in response to the removal of competition (*17*) and was thought to require from 5 to 10 years.

However, a study in southeastern Virginia showed that released trees increased their cone production substantially in the third year and maintained the greater production through the fourth and fifth years after release (fig. 10). One hundred and fifty-six vigorous well-formed dominant and codominant trees were selected at intervals of 50 to 60 feet in 3 old-field stands. The stands were 27, 33, and 43 years old and the site index was 80 to 85 feet. Trees were paired according to their similarity in diameter, height, width and length of crown, age, and size of current cone crop, and one of each pair was released. Enough competitors were cut around each selected tree to put it in an opening 2½ to 3 times its crown width, which resulted in a 20-foot radius, on the average, being cleared around each released tree (fig. 11). The release cutting was done during the winter of 1946–47. Cones were counted on the standing trees from 1946 to 1951. Beginning in 1949, about one-third of the trees, equally divided between released and control, were cut each year and exact counts of sound and defective cones made. Two sound cones were taken

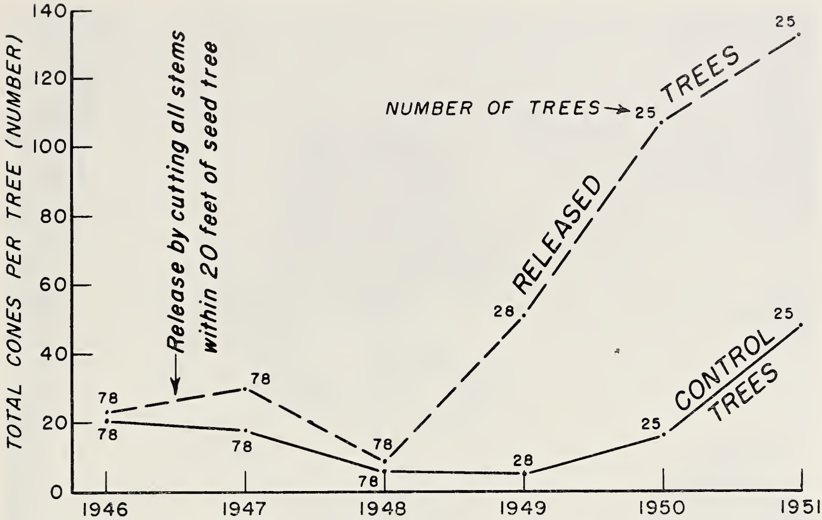

FIGURE 10.—Trend of annual cone crops of released and control trees. Trees were released in the winter of 1946–47 *(103)*.

from each felled tree in 1950 and 1951, the seeds were extracted and cut, and sound and defective seeds were counted.

Thus the release cutting in the winter of 1946–47 was immediately effective; that is, an increased number of flower buds was formed during the first growing season after release. The effect of release cannot be reflected in cone production in less than 3 growing seasons because cones need 2 growing seasons to mature, and flower buds must first be formed. These results are not those of an isolated situation; a similar third-year increase has been observed in a shelterwood stand in central North Carolina (*76*), 2 seed-tree stands (*101*) and 2 thinned stands in southeastern Virginia, and 2 seed-tree stands in eastern South Carolina (*27, 52*), and in 3 different kinds of stands in the Bigwoods Experimental Forest (table 1).

TABLE 1.—*Seed production in the Bigwoods Experimental Forest, by stand description and number of growing seasons since cutting*

Stand description	First growing season after cutting	Seed produced when number of growing seasons after cutting is—					
		1	2	3	4	5	6
Selection stand:	*Year*	*Thousand*	*Thousand*	*Thousand*	*Thousand*	*Thousand*	*Thousand*
A	1947	366	50	191	399	275	143
B	1948	50	56	457	646	353	
Seed strips:							
A	1946	124	134	147	183		
B	1946	128	147	156	193		
8 seed trees	1948	17	34	373	528	316	34
2 seed trees	1950	36	15	52			

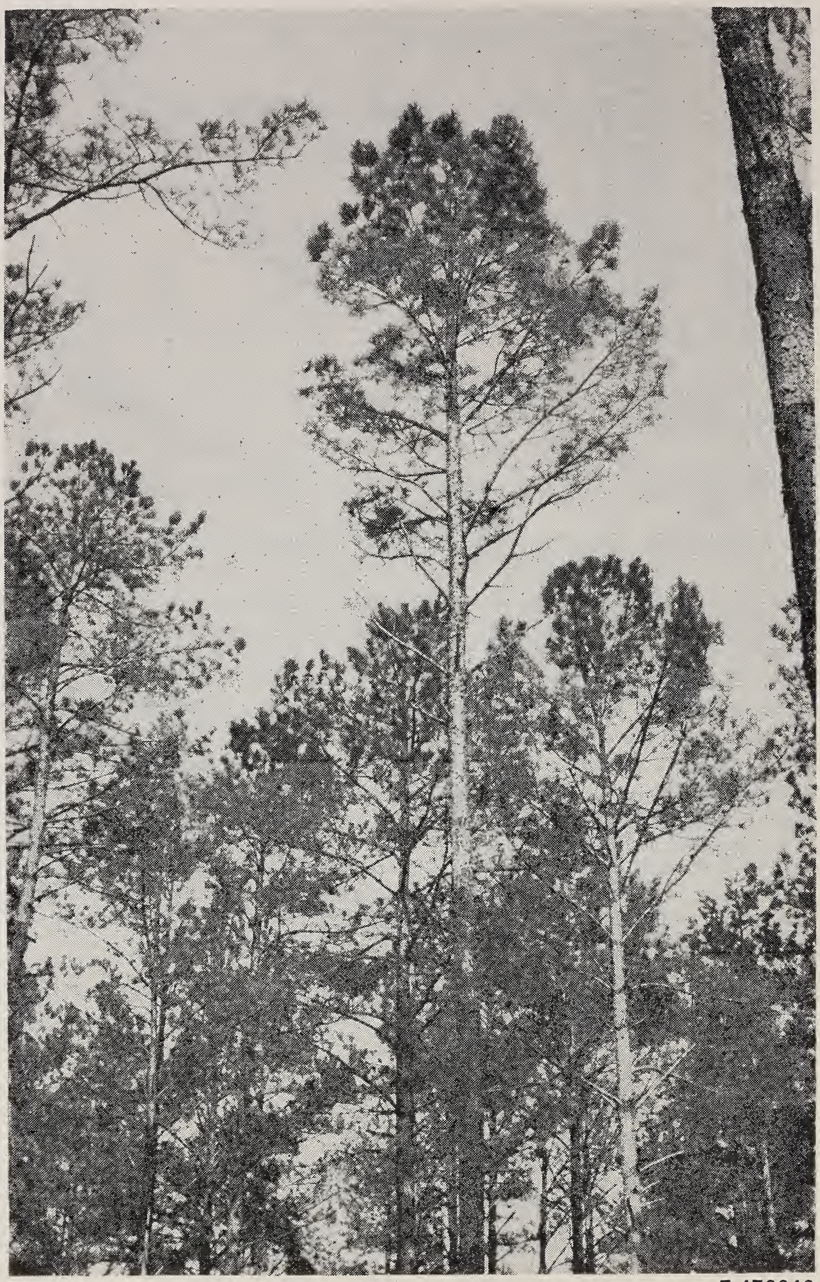

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FIGURE 11.—A released tree, showing the size of the opening that relieved the tree from competition and brought about a substantial increase in cone crops.

The seed production in the Bigwoods stands was determined both by seed trapping and by general observation. Stands cut during the growing season showed the effect of release in the third or fourth crop after cutting, depending on whether they were cut early or late in the season. The critical period in that locality seems to be some time during late June or early July, the date probably varying considerably from year to year. The increase in cone production following release is evidently not a result of crown and root expansion but of a change in the internal nutrient status soon after the tree is freed from competition.

Large trees produce many more cones after release than small trees (fig. 12). And trees that have been fruitful in the past produce much larger crops after release than trees of lesser previous fruitfulness (fig. 13). In addition, response to release apparently is strong enough to overcome most of the unfavorable factors that cause poor seed years. The increase in cone crop caused by the individual crown release described above occurred in 1949, one of the poorest seed years on record (*87*). In the same year a selection stand cut 3 years before produced nearly 4 times as much seed as another similar stand that was cut a year later and could not yet show any response to release (table 1). However, the larger seed crop failed to attain the bumper level of 1947 in the same stand by a substantial margin. The third-year seed crop of two strip cuttings remained at the bumper level of 1946 and 1947 in the face of a very low regional level in 1948 (*87*).

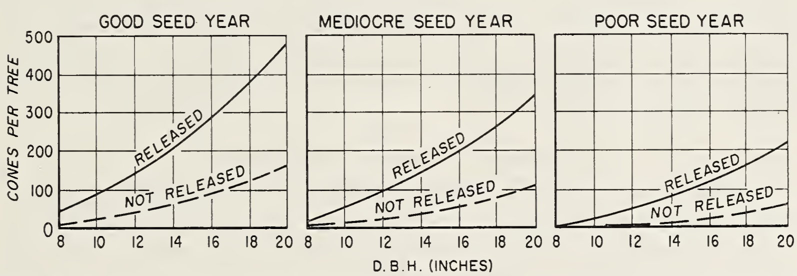

FIGURE 12.—The number of sound cones per tree in relation to the diameter at breast height for released trees and trees under stand competition.

The evidence indicates that the third-year increase can be expected regardless of the general trend of cone crops in uncut stands, although the increase may not be so great in poor as in good seed years. Rather infrequently, extreme weather conditions may nullify the increased flowering induced by release. Hail or subfreezing temperatures may destroy the flowers locally, rainy weather may inhibit or prevent pollination, or drought may retard cone and seed development. Such retardation apparently occurred in eastern Virginia during the extreme drought of 1953, when a moderately good cone crop produced very few seed. A severe frost in late March 1955 completely destroyed the flowers over a wide area, and a cone crop failure in 1956 was the result.

Although response to release is maintained beyond the third year, it eventually seems to subside. The seed crops of the released

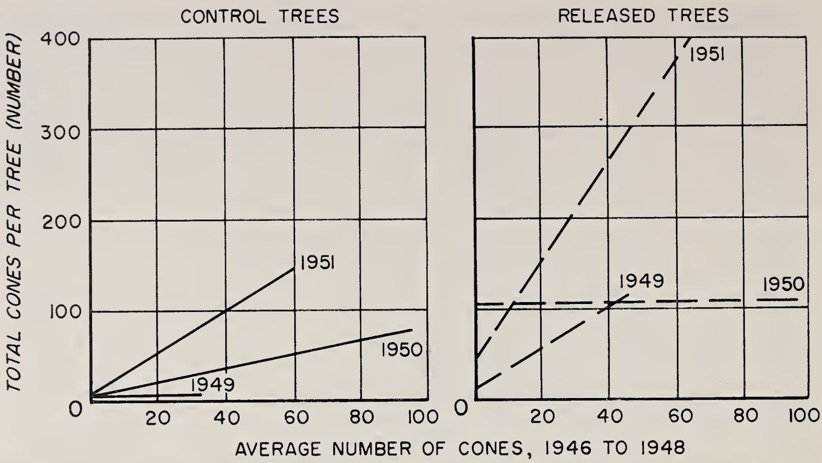

FIGURE 13.—The number of cones per tree in relation to past fruitfulness. The lack of a relation among released trees in 1950 is attributable to one exceptionally responsive tree; without it, the relation for the mediocre seed year of 1950 falls between the poor year of 1949 and the good year of 1951 *(101)*.

trees then again follow the regional trend, but probably at a higher level than before release. Easley (*27*) observed a marked decline in the seventh year after release, or in the fifth affected seed crop. A stand in southeastern Virginia from which approximately half the volume had been removed showed a continuous, uninterrupted decline from the increased third crop to the sixth, the last observed.[13]

Response to Fertilizer and Injury

The success enjoyed by agriculturists in increasing the yield of field, forage, and orchard crops suggests that fertilizer might also be used to increase the production of forest tree seed. According to the few records available, fertilizer may substantially increase the seed production of some forest species (*16*, *25*, *31*). Partial girdling and banding have also been used in Europe for many years to increase the yield of fruit trees (*49*) and have been tried experimentally on forest trees (*1*, *78*). An exploratory study in southeastern Virginia indicated, however, that these treatments would probably have very limited application in the natural regeneration of loblolly pine stands (*101*).

The effects of fertilizer and partial girdling were studied in two seed-tree cuttings made in the winter of 1947–48 (fig. 14). The partial girdle was made by a knife cut through the bark to the wood halfway around the stem 3 feet from the ground. The fertilizer was of 7–7–7 analysis and was spread on the ground around the tree to 2 feet beyond the edge of the crown. Both 25 and 50 pounds of fertilizer per tree were tried. In each stand each treat-

[13] Wenger, K. F. Seed tree development study. Unpublished report on file at the Southeast. Forest Expt. Sta.

ment was applied to 25 trees. The soil was Norfolk loamy sand to sandy loam, and the site index was 80 feet at both locations.

No increase in cone crop followed partial girdling in either stand, apparently because the knife cuts healed over before bud formation. The treatments were applied late in April, and by the end of June all knife cuts had healed.

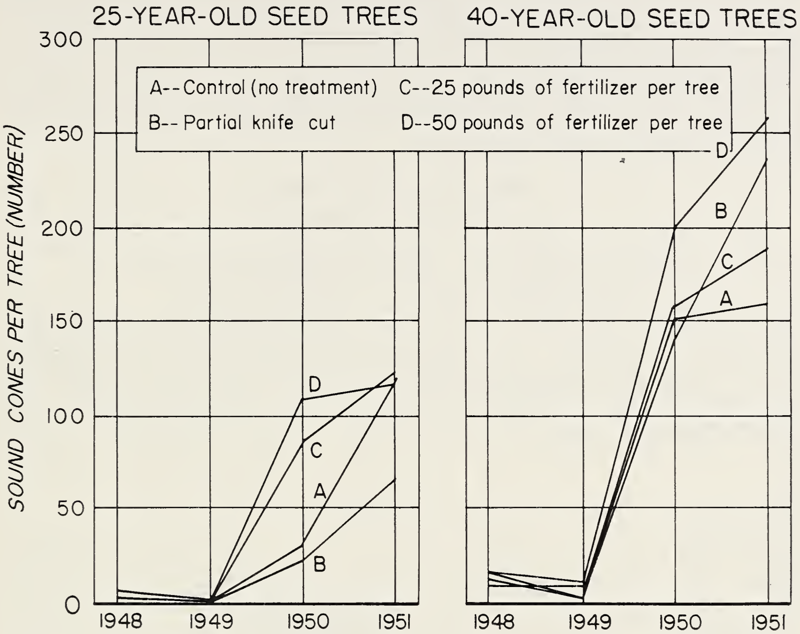

FIGURE 14.—Trend of annual cone crops of fertilized, partially girdled, and untreated seed trees. The seed-tree cutting was made in the winter of 1947–48 *(101)*.

In the younger (25-year-old) stand, both lightly and heavily fertilized trees produced significantly more cones than the check trees in the first effective year (the third growing season after treatment), but the production of the heavily fertilized trees was not significantly greater than that of the lightly fertilized trees. Most of the additional 25 pounds of fertilizer was apparently superfluous. In the next year the fertilized trees produced no more cones than the unfertilized controls. The response to fertilizer only in the first effective year indicates that its effect was directly nutritional rather than indirectly through the development of more foliage and an increase in reserve carbohydrates, as seems to be true with deciduous species *(16)*.

Although the level of cone production in the older stand was much higher than in the younger, the effect of fertilizer was not significant. The large increase in cone crops in 1950 was caused mainly by release of the trees in 1948, since it occurred just 3 years later in the face of generally unfavorable conditions. The great response to release may have obscured the effect of fertilizer,

or the amount of fertilizer applied may not have been enough for the larger trees. The larger cone crop of the heavily fertilized trees, although not significant, does suggest an effect of fertilizer that might have been enhanced by heavier applications.

Nor did fertilizer contribute much to the further increase in cone production by either of the two age classes in 1951, since cone crops on fertilized trees were not significantly larger than those on unfertilized trees. The increase was apparently caused partly by the continuing effect of release and partly by the improvement in climatic and cyclic factors.

None of the treatments significantly changed the percentage of defective cones, the total number of seeds per cone, or the percentage of sound seeds per cone.

Dissemination of Seed

The distance to which various amounts of seed were carried across a clear-cut strip from adjacent uncut strips was observed in the Duke Forest (*40, 56, 76*). Eighty-five percent of the total seed released fell within 200 feet of the windward uncut strip. The seedfall within 100 to 200 feet was 17.5 percent of the total, but within the next 100 feet (200–300 feet from the windward strip) the seedfall dropped to 8.3 percent of the total. A slight rise in seedfall at the extreme distance was due to seed from the next uncut strip (fig. 15).

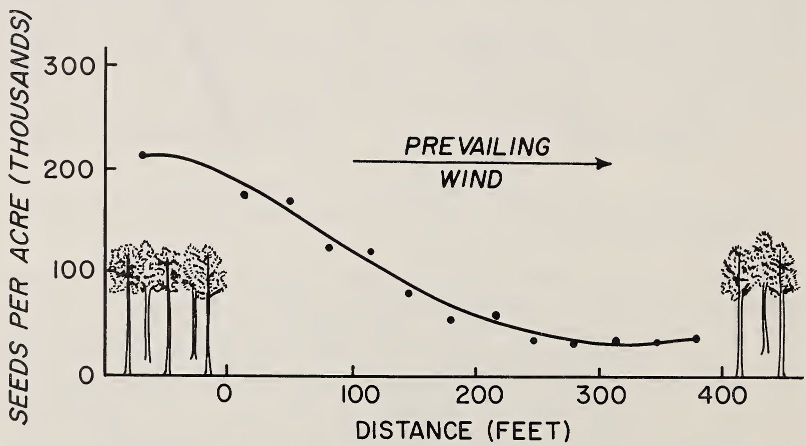

FIGURE 15.—The distance to which seed is carried, on the average, from a seed strip across an adjacent clear-cut area *(75)*.

The distribution of seedlings in old fields shows that a close relation exists between the pattern of seed dissemination and the establishment of seedlings. McQuilkin (*68*) found that the quality of the seed source and the distance from the seed source are the most important factors controlling the establishment of pine in old fields. The density of seedlings begins to decline between 1 and 2 chains from a good seed source. A density of 1,000 seedlings per acre did not occur, on the average, more than 5 chains (330

feet) from the seed source, and 500 seedlings per acre did not occur beyond 7 chains (462 feet). Beyond seven chains, seedling establishment was erratic and uncertain and seldom approached satisfactory levels. This distribution of seedlings agrees well with the seed dissemination pattern described above if allowance is made for reduced wind velocity in the relatively narrow clear-cut strips in which seed dispersal was observed (*40*).

It is evident, therefore, that effective quantities of seed are carried at least 200 feet from the source, providing, of course, that ample quantities are produced. This information applies mainly to the spacing of the uncut strips in strip cuttings. In stands of scattered seed trees the distance to which seed will be carried is not so important. The number of seed trees that must be left for a satisfactory number of seedlings is such that their spacing is well within the effective seeding distance.

REQUIREMENTS FOR GERMINATION AND INITIAL ESTABLISHMENT

Measures to provide adequate supplies of seed may be largely ineffective if the conditions for germination and initial establishment are unfavorable. The seedbed requirements for loblolly pine have been known in a general way for many years (*2*), but more recent information shows that certain seedbed conditions are essential for successful regeneration.

Seed Losses

While the seed are on the ground during the dormant season, rodents and birds probably eat an appreciable number. The rodent population usually is small in the uncut forest, but after clear cutting it increases rapidly. In the Bigwoods Experimental Forest, it reached a peak within the first year after clear cutting and remained at a relatively high level through the fourth year (*90*). Seed requirements, on the other hand, increased steadily during the same period. These two divergent trends indicated that rodents are not a major cause of seed losses. Consumption by birds is probably on a similar scale, accounting for appreciable amounts of seed but not usually to the extent of being a determining factor in seedling establishment. Occasionally a large flock may consume most of the seed in a limited area. Observation of protected and unprotected quadrats over a 3-year period on the Santee Experimental Forest showed that rodents and birds accounted for 22 percent of viable seed. Germination in the protected quadrats compared to the fall of viable seed also suggested that more seed was lost to other factors than to rodents and birds.

Germination

Germination begins in the spring when temperature becomes favorable, usually at about the same time that established trees begin vegetative growth. Temperatures below 40° F. preclude germination, and the best range is 65° to 80° F. (*93*). Most germination takes place early in the growing season but may continue well into the summer.

A critical factor in germination is the availability of sufficient moisture. Ample moisture is needed to initiate germination and to sustain the seedling until roots develop. Moisture conditions are most favorable on newly exposed mineral soil. Thus, loblolly pine seed germinates more readily on mattocked, plowed, or raked soil surfaces than on undisturbed litter (*28*, *32*).

Pomeroy (*74*) tested germination of loblolly pine seed on samples of 3 surface conditions, 2 kinds of litter, and 3 soil-texture classes. On exposed mineral soil 91 percent of the seeds germinated, a significantly higher percentage than on undisturbed surfaces, where 67 percent germinated. On burned surfaces the germination percentage varied with the intensity of burning. When all the litter was burned and the mineral soil exposed, germination was similar to that on unburned mineral soil, 85 to 99 percent. When less intense burning left a layer of litter, 35 to 86 percent of the seeds germinated. Under field conditions, where water is not regularly supplied, moisture may often be deficient and germination percentages lower.

In addition to germination failures, 45 percent of the seeds that germinated died, mainly because of failure to root. Upon emergence, the radicle turns downward. If it cannot penetrate the soil and remain in contact with a moisture supply, the seedling soon dies. Losses for that reason were heaviest on burned or exposed surfaces of heavy clay soils. These soils may bake during or after a clean burn, or may become puddled by heavy logging equipment. Radicles of germinating seeds could not penetrate such surfaces, unless they happened to lodge in cracks that occur as the clay soils dry and shrink. Appreciable numbers were also killed by fungi and insects.

Survival

Conditions that are unfavorable for germination are also unfavorable for survival and growth. Where the litter remains, competing vegetation is also likely to be present. Thus, differences in fresh seedbed conditions are reflected to a greater degree by numbers of seedlings at the end of the first growing season than by germination percentages. The following tabulation shows the effect of soil disturbance on establishment of seedlings from 86,000 sound seeds per acre in the first year after seedbed preparation (*77*).

Surface condition:	*Seedlings per acre*
Bare soil	12,107
Some disturbance	8,796
Severely burned	8,364
Medium burned	5,882
Lightly burned	7,077
Undisturbed	2,600
Slash	1,062

These effects of seedbed conditions on seedling survival apparently hold true in general throughout the commercial range of loblolly pine. After a heavy seedfall in southeastern Arkansas,

Grano (*34*) found 43,100 seedlings per acre at the end of the first growing season on newly exposed mineral soil, 8,300 seedlings on undisturbed litter, and only 1,300 seedlings on logging slash. He also found twice as many seedlings on pine as on pine-hardwood litter, and twice as many on pine-hardwood as on pure hardwood litter. Pine seedling establishment was directly related to depth of litter, ranging from 26 seedlings per milacre plot where the litter was 0.0 to 0.5 inch deep to 1 seedling where the litter was 3.0 to 3.5 inches deep.

The greatest mortality occurs early in the first growing season, shortly after germination (*28*). In the Bigwoods Experimental Forest, mortality in the first growing season averaged 7.5 percent in 1 year and 18.0 percent in another year, with a distinct tendency to be higher in lighter soils.[14] These observations indicate that moisture is still the most important factor in survival of seedlings after germination. Pales weevils, grasshoppers, ants, and rabbits may also destroy appreciable numbers of seedlings, but they apparently have not caused critical losses of natural reproduction in the South Atlantic Coastal Plain.

Seed Requirements

Seed losses, germination failures, rooting failures, and seedling mortality are reflected in the large numbers of sound seeds required, even on the best seedbed, for seedling establishment. Records of seedfall from seed trees or seed strips and seedling establishment in clear-cut tracts in the Bigwoods Experimental Forest showed that where litter had been disturbed and mineral soil exposed, 9 sound seeds were required, on the average, to establish 1 seedling in the first year after logging or seedbed preparation (*85*). Seedbed conditions are not completely uniform, however, and moisture supplies vary from year to year; consequently, seed requirements also vary. Thus, the average of 9 seeds required on bare soil represented a range of 4 to 25 seeds. On burned soil surfaces the number of seeds required ranged from 6 to 30 and averaged 15. On undisturbed litter or slash, seed requirements varied much more, ranging from 5 seeds up to an unlimited number where no seedlings survived to the end of the first growing season. Average requirements were over 40 seeds per seedling.

A comparison of seedfall and seedling establishment on a gravelly clay in the upper Coastal Plain of Virginia—conditions in sharp contrast to those in the Bigwoods—showed that seed/-seedling ratios were of similar magnitude in the two localities (*67*). Probable seedling establishment was estimated on the basis of sound seed per acre and the proportions of the tract in different seedbed conditions. The estimate was that 1,268 seedlings per acre, distributed to yield 48 percent milacre stocking, would be established. Observed seedling establishment was very close to the estimate: 985 seedlings per acre, amounting to 49 percent stocking, were present at the end of the first growing season.

[14] Trousdell, K. B. Seedling mortality. Memoranda on file at the Tidewater Forest Research Center, Franklin, Va.

Seedbed conditions are most favorable for seedling establishment in the first year following logging or preparatory treatment. They deteriorate rapidly thereafter, and by the third year approach an undisturbed state (*89*). This deterioration is reflected in the increased number of seeds required in the second and later years for seedling establishment in the Bigwoods Experimental Forest (table 2). On the average, 3 to 4 times as many seeds were required to establish a seedling in the second year as in the first year after logging or seedbed preparation. By the third year the requirement had risen to more than 10 times that in the first year. Observations of seedling establishment in successive years made by Meyer (*69*) showed that seedbed conditions deteriorated with equal rapidity in southeastern Arkansas (*106*).

TABLE 2.—*Sound seed required to establish an additional seedling at the end of the growing season, by seedbed condition*

Initial seedbed conditions	First year	Second year	Third year	Fourth year
	Number	*Number*	*Number*	*Number*
Disturbed	9	36	126	167
Burned	15	47	134	----------
Undisturbed	46	----------	427	156
Slash	41	331	365	336
Average, all tracts	14	50	162	143

The increase in seed requirements with age of seedbed is probably due mainly to lower germination and heavier mortality from competition. In Arkansas, substantial numbers of new seedlings present early in the growing season of the third and later years had disappeared by spring of the following year (*69*). Woody and herbaceous vegetation develops rapidly in clear-cut areas, producing a new mantle of litter that retards germination, and the mortality of new seedlings is undoubtedly increased by the heavier brush competition.

Initial Growth

Soil surface conditions affect not only germination and first-year survival but also height growth during the first growing season. Pomeroy and Trousdell (*77*) found that 1-year-old seedlings were tallest on severely burned and moderately burned surfaces; somewhat shorter on bare soil and disturbed surfaces; and shortest on lightly burned surfaces, on undisturbed litter, and in slash piles (fig. 16). These differences in rates of height growth are probably due to earlier germination on the favorable seedbeds, which results in a longer initial growing season. In addition, burning releases mineral nutrients in the litter, increases the amount of nitrogen, and lowers the acidity of the surface soil (*38*).

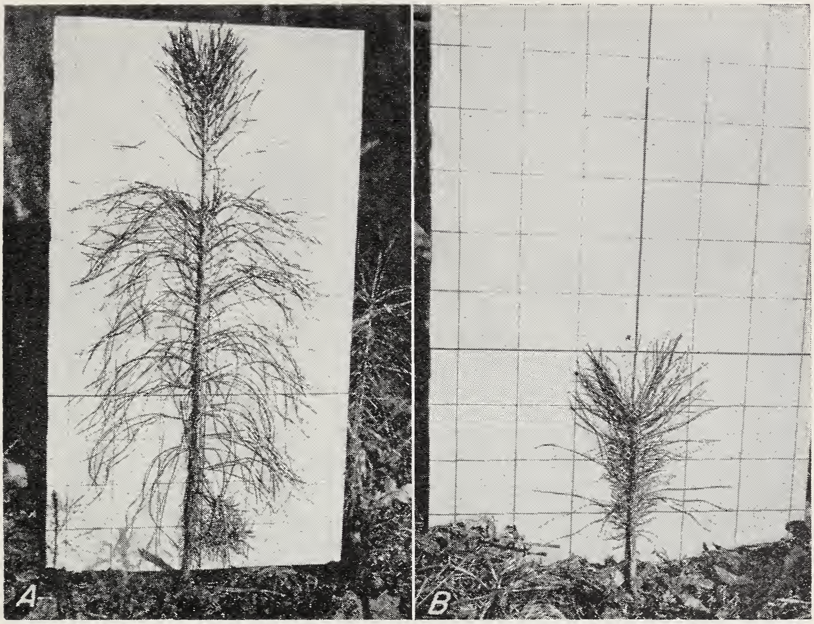

FIGURE 16.—One-year-old loblolly pine seedlings: *A*, 22–inch seedling in a severely burned area; *B*, 6–inch seedling on lightly disturbed litter. (Background is divided into 2–inch squares.)

METHODS OF NATURAL REGENERATION

Consistent success in reestablishing loblolly pine by natural seeding can be attained only if the behavior and requirements of the species are taken into full account. Sufficient seed is an absolute requirement, for without it failure is certain. Measures to supply seed must be carefully planned, not only in accordance with seeding characteristics but also with respect to seedbed conditions. Because it is adaptable to a wide range of environmental conditions, loblolly pine can be regenerated in either even-aged or uneven-aged stands. For either, however, ample seed and a favorable seedbed must be provided, and some measure of control exercised over the more aggressive competitors.

Even-Aged Management

Seed Source

Loblolly pine is a comparatively prolific seeder, but sparse reproduction often results when its seeding characteristics are ignored in harvest cutting. Seed sources in even-aged management are usually of three types: a few, scattered, individual trees; heavier, partially cut stands sometimes called shelterwood stands; or uncut strips (fig. 17). The shelterwood stands can also be regarded as stands of many seed trees. The number of seed trees that should be left to give a reasonable assurance of satisfactory

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FIGURE 17.—Seed sources in the Bigwoods Experimental Forest: *A*, Eight seed trees per acre; *B*, strips 1 chain wide 3 chains apart, edge to edge.

reproduction can be approximated, providing a goal of stocking[15] is set, the size of the trees is taken into account, and seedbed conditions on the tract in question are known.

The data from the studies on cone and seed production and on seedbed requirements were used to determine approximately the minimum number of seed trees of different sizes needed to produce several levels of stocking of reproduction on different types of seedbed (table 3). These requirements are based on the average production of sound seeds of well-formed healthy dominant and codominant trees in uncut stands ranging from 27 to 43 years in age. They are a guide rather than a firm prescription and apply to the seed-tree method as it has usually been practiced, where the seed trees get no release in advance of the harvest cut.

The basic requirements can be adjusted to apply to the aggregate seedbed conditions created by different methods of seedbed preparation (footnote, table 3). A further adjustment may be made if past fruitfulness is considered when the seed trees are marked. The requirements were computed on the basis of the average production of sound seeds of dominant and codominant trees within each diameter class. However, in choosing seed trees, the better-than-average cone producers, as indicated by a greater number of old cones in the crown, should be favored. Because of the large variation in cone production of otherwise similar trees, there should be enough trees with at least twice the average production in any stand to serve as seed trees, particularly if considerable leeway is allowed in spacing. For example, in a moderately good seed year the production of 10-inch trees ranged from 0 to 97 cones, 12-inch trees from 0 to 59 cones, and 14-inch trees from 0 to 110 cones. Since it has also been shown that the more fruitful trees continue so, the number of seed trees required can probably be reduced by one-third to one-half if the most fruitful are chosen.

On poor sites the number of seed trees probably should be increased. The stands that furnished the data on seed production were growing on sandy loam soils with a site index of 80 to 85 feet, which is somewhat above the average for the Coastal Plain. Thus, the area, although typical of much of the well-drained upland in the South Atlantic Coastal Plain, furnished no basis for determining seed-tree requirements on poor sites. However, with some increase in the number of trees and with greater

[15] The term "stocking" refers to the percentage of quadrats of specified size (usually 1 milacre) containing one or more established seedlings, rather than to the number of seedlings per acre. How well a tract is stocked by a given number of seedlings depends on their distribution. The relation derived from reproduction surveys in the Bigwoods Experimental Forest shows that the following numbers of seedlings are needed to yield the specified levels of stocking in clear-cut areas (*85*):

Seedlings per acre	*Milacre stocking (percent)*
600 – 1300	40
1300 – 2500	60
2400 – 4200	75
4900 +	90

A stocking percent thus reflects the distribution as well as the number of seedlings and is, therefore, the most useful expression of the amount of reproduction in an area (*33*, *41*, *54*).

TABLE 3.—*Approximate minimum number of loblolly pine seed trees per acre needed to attain the specified stocking of reproduction in the first year after tractor logging*[1]

Desired reproduction (percent of milacres stocked)	Seed trees per acre when diameter at breast height in inches is—						
	8	10	12	14	16	18	20
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
GOOD SEED YEAR							
40	43	17	9	5	4	3	3
60	-------	37	19	11	7	5	3
75	-------	67	35	20	13	9	6
90	-------	-------	70	41	25	17	12
MEDIOCRE SEED YEAR							
40	-------	38	18	10	6	4	3
60	-------	82	38	21	13	9	6
75	-------	-------	69	39	24	16	11
90	-------	-------	-------	79	49	33	23
POOR SEED YEAR							
40	-------	-------	67	32	19	12	8
60	-------	-------	-------	69	40	25	18
75	-------	-------	-------	-------	73	47	32
90	-------	-------	-------	-------	-------	-------	65

[1] The numbers of trees shown are those required to attain the specified stocking of reproduction on the logged area as a whole, rather than on a single seedbed condition. To determine the number of seed trees needed on areas where burning or disking has been done in addition to logging, multiply the tabular figures by the following factors: logged and burned—⅔, disked and logged—⅓.

Not less than three trees per acre should be left under any conditions, since wider spacing might prevent adequate pollination and reduce seed production.

emphasis on fruitfulness, satisfactory amounts of seed can probably be obtained.

In addition to diameter and fruitfulness, crown class must also be considered. Seed trees should always be chosen from among the dominant and codominant trees in the stand (fig. 18). In older stands or on better sites, trees as large as 14 or 16 inches in diameter may be intermediate or even suppressed, and incapable of adequate seed production. Furthermore, their inferior position may be the result of an inherently slower rate of growth.

Undesirable hereditary factors may also be reflected in poor bole form, forking, large and upswept branches, and the presence of disease or insect infestation. Although it is impractical to examine closely each prospective seed tree for defective cones, trees with an obviously large percentage of defective cones are occasionally encountered. Insect attack tends to remain at a high level in such trees, and they should be passed over in seed-tree marking.

The number of seed trees left depends on whether they are to be cut when reproduction is established. If they are not to be cut at that time, the amount they contribute to the cost of establishing the new stand must be considered. They probably will not be

F-479362

Figure 18.—A good 40-year-old seed tree. The straight stem and slender, horizontal branches indicate good genetic constitution, and the large number of old cones in the well-developed crown show that the tree is likely to produce large amounts of seed in the future.

left indefinitely, since those that remain can be recovered when cutting begins in the new stand. Thus the charge against the new stand is the value of all the seed trees carried at compound interest minus the value of those that are recovered during cuttings in the new stand. With younger trees, value growth might easily exceed interest charges, but whether the excess would be enough to compensate for mortality is questionable. Consequently, only the minimum number required for regeneration should be left.

The usual reason for leaving seed trees beyond the regeneration period is to reestablish the stand in case of destruction by fire. However, the decision to leave the seed trees for a long time should be weighed against the alternative possibility of planting if the reproduction is destroyed. In much of the South Atlantic Coastal Plain the risk of fire is probably low enough so that the most profitable procedure is to harvest the seed trees and, if a fire occurs, replant.

If the seed trees are to be harvested, enough should be left to make an operable cut. Sometimes, particularly in good seed years, the number to be left may be more than the minimum required for regeneration. However, in the Bigwoods Experimental Forest, harvests of as few as two seed trees per acre have been profitable. Removing eight trees per acre has been as profitable as any other kind of harvest cutting (table 4). These were big trees, 8 averaging 4,000 board-feet per acre. Nevertheless, the cost of harvesting seed trees of any size should be no greater than the cost of other kinds of cutting, if the seed trees are chosen from the biggest and best trees in the stand and their total volume is operable.

TABLE 4.—*Cost of logging in relation to method of cutting*

Method of Cutting	Volume cut per acre	Hours per M board-feet			Estimated cost per M board-feet tree to truck[1]	Tracts
		Labor and super-vision	Trac-tor	Loader		
	Board-feet	*Number*	*Number*	*Number*	*Dollars*	*Number*
Clear cut leaving 8 seed trees	20,218	5.26	0.44	0.35	9.48	6
Clear cut leaving 1-chain-wide strips	16,769	6.81	.53	.42	11.89	8
Initial selection cutting	8,236	6.36	.54	.36	11.40	5
5-year selection cutting	3,070	6.12	.54	.41	11.26	6
Annual selection cutting	521	6.75	.55	.41	11.95	5
Remove seed trees	3,122	6.24	.61	.38	11.88	10
Remove strips	4,296	5.69	.53	.37	10.67	8

[1] Computed at rates of $1.00 per man-hour, $8.00 per tractor hour, and $2.00 per loader hour. All skidding was in tree lengths, and all operations were by the same logging crew with the same crew organization and kind of equipment.

The trees should be cut as soon as possible after satisfactory reproduction has been established. As seedbed conditions deteriorate, seed trees rapidly become ineffective, and losses from wind, lightning, and other causes become substantial in a few years (table 5). Trousdell (*91*) found that mortality averaged about 1 percent of the number of seed trees per year and was greatest within the first few years after harvest cutting, apparently because of damage and injuries that occurred during logging and other activities. In the first 3 years, 50 percent of the mortality was caused by logging and fire damage, insects, and miscellaneous agencies, and 50 percent by wind and lightning. In the fourth to the sixth year, wind and lightning caused 95 percent of the mortality although total losses were only about one-fourth as great as in the preceding years.

Much of the mortality attributed to logging occurred near loading decks and skidroads on heavy, poorly drained soils that were wet and became puddled, sometimes to a depth of 1 or 2 feet. Nearby seed trees undoubtedly lost much of their root systems. And the puddled soil probably retarded aeration. The trees died

rather slowly, showing symptoms of nutritional deficiency—a progressive yellowing and thinning of the foliage and gradual dying of the crowns over a period of 1 to 3 years (*63*). Lightning losses were proportional to the area in seed trees and accounted for 2 trees per 100 acres per year regardless of the number of trees present.

TABLE 5.—*Annual mortality of seed trees in relation to cause, number per acre, and stand origin* (*91*)

Stand description	Seed trees killed annually per 100 acres			
	Lightning	Wind	All other causes	All causes
	Number	*Number*	*Number*	*Number*
8 seed trees per acre:				
Old field	2.1	2.5	2.8	7.4
Forest grown	2.1	.5	5.8	8.4
Average	2.1	1.8	3.9	7.8
2 seed trees per acre:				
Old field—from 8 seeds trees	2.2	2.8	0	5
Forest grown—from 8 seed trees	2.1	3.2	.7	6
Forest grown—from strips	1.9	0	.6	2.5
Average	2	1	.5	3.5

In addition, damage to reproduction will be less if seed trees are removed while the seedlings are small, especially if some care is taken in logging (*88*, *109*). Trousdell (*88*) found that tractor logging of eight seed trees per acre in tree lengths caused heavy damage to reproduction on only 7 to 8 percent of the area, mostly at loading decks and along main skidroads. Light damage occurred on about an equal percentage of the area. One- and two-year-old seedlings, because of their small size and flexible stems, often survived the passage of tractor treads. Older seedlings broke much more readily. Damage to reproduction is undoubtedly related to the number of trees removed. Where the seed source consists of many seed trees—that is, so-called shelterwood stands—much more damage probably will occur during its removal. Damage can be held to a minimum by felling in the direction of skidding, and skidding in straight lines toward main skidroads or loading decks with no more turning than absolutely necessary.

Removal of the seed trees will be easier if they are left in lines rather than scattered over the area. Logging activities and attendant damage to the reproduction can then be confined to narrow strips.

Leaving the seed source in the form of uncut strips rather than in scattered seed trees has some advantage in that marking is simpler, since it can be done faster and more systematically, and the removal of strips does not require so much care to avoid damage to reproduction. On the other hand, regeneration of the area in uncut strips must be provided for when the strips are removed. The seed supply cannot be controlled in strip marking as it can be in seed-tree selection, and the seed production of the strips may not be so great as that of scattered seed trees. Strip cuttings in the Bigwoods Experimental Forest left one-fourth of

the stand in uncut strips 1 chain wide and 3 chains apart, edge to edge. The seed production of such strips was considerably less than that of stands of eight scattered seed trees per acre in the same years and before the response to release was reflected in the seed crop. Seed production of these two areas is as follows:

	Seed production per acre	
	1950 (thousands)	*1951 (thousands)*
Stand description:[1]		
Uncut strip	42	84
Eight seed trees per acre:		
Stand A	69	189
Stand B	110	198
Stand C	—	173

[1] Site index, stand age, and volume were similar before harvest cutting.

The distance between edges of seed strips should not be more than 200 feet, since relatively few seed are carried to greater distances from the source. Although supporting data are lacking, the width of the seed strips is probably not so important. Most seed falling in the clear-cut strip probably comes from the trees at the edge of the seed strip. Thus, it does not seem likely that increasing the strip width would result in a proportionate increase in the amount of seed cast. Furthermore, less area needs regeneration at the time of strip removal when the seed strips are narrow.

Seed strips may be thinned at the time of harvest cutting to open the canopy to the wind and so promote seed dispersal. However, except for the removal of merchantable understory hardwoods, the Bigwoods cuttings were not done in this manner, and no data are available to show whether thinning the strips does in fact increase seed dispersal. A real advantage of thinning the strips is that the strip removal will be a more profitable operation. The trees that are left will be the larger, better quality trees and, therefore, cheaper to log.

After satisfactory reproduction has been established in the clear-cut strips, the seed strips should be removed during the dormant season, after seedfall and before germination in the spring. Seed will be on the ground, and the logging will disturb the litter on much of the strip area. Although some seed may be buried too deeply to germinate, most will remain on or near the surface. Satisfactory reproduction has been obtained in all seed strips in the Bigwoods.

In removing the seed strip, tractor travel should be kept within strip boundaries. The log loader can be set up at a convenient place within the strip, and trees can be felled parallel to the strip. Thus, tractor travel in the adjacent clear-cut strip can be kept to a minimum and damage to reproduction avoided. This procedure has been consistently followed in removing seed strips in the Bigwoods without particular difficulty and without incurring any extra cost.

The cost of removing strips in the Bigwoods was slightly less than the cost of the harvest in the clear-cut strips (table 4). Since both cuts were in the same tracts, the small difference is probably within the normal range of variation.

Seedbed Preparation

Logging with crawler tractors creates favorable seedbed conditions on substantial portions of the logging tract (fig. 19). However, the importance of seedbed conditions in pine establishment—indicated by the seeds/seedling ratios on different seedbeds—justifies additional efforts to increase the favorable area.

F-479342

FIGURE 19.—Tractor logging in a clear-cut strip has destroyed most of the understory hardwoods and exposed mineral soil on much of the area; thus a good seedbed results.

Where logging is done with wheeled tractors and carts, the forest floor is disturbed very little and additional measures to provide a favorable seedbed become essential. In widely spaced trials in the Southeast of seed-tree, shelterwood, and diameter-limit cuttings in pulpwood-size loblolly pine stands, no seedbed preparation was made and the logging was done with animals and trucks. Nine years later reproduction was still unsatisfactory, in spite of a gradual increase during the period (*59*). Only in the shelterwood cuttings, where 40 of the best trees per acre remained to supply seed, did enough pine seedlings become established near the end of the period to provide fairly good stocking after the removal of the overstory.[16] Although the age of the stands—all less than 40 years and often less than 30—was probably an important factor in the poor regeneration, intensive seedbed preparation would undoubtedly have hastened seedling establishment and pushed the stocking toward satisfactory levels.

[16] Pomerening, D. A. Results of the two-cut shelterwood method in loblolly pine pulpwood-size stands in the Carolinas and Virginia. 1951. (Unpublished master's thesis, School of Forestry, Duke University, Durham, N. C.)

Burning, scarification, and bulldozing have been widely used for seedbed preparation in the Southeast. Usually, the destruction of hardwoods is the primary purpose of these methods, but they also result in good seedbed conditions. This dual function is commonly recognized, and the cost of the operation charged to both seedbed preparation and hardwood control. A variety of devices to scarify the ground and destroy hardwoods has been tried, but in the South Atlantic Coastal Plain heavy bush-and-bog diskharrows have been the most popular.

The area in favorable seedbed conditions can be substantially increased by disking with a bush-and-bog diskharrow before logging or by burning after logging (fig. 20). Tractor logging creates favorable seedbed conditions on about 50 percent of the logged area; disking or burning increases that percentage to 80 to 85 percent. The percent of area in each seedbed condition for three methods of site preparation is as follows (*85*):

Seedbed condition:	*Logging (percent)*	*Logging and burning (percent)*	*Disking and logging (percent)*
Disturbed	49	35	79
Burned	0	49	0
Undisturbed	31	15	4
Slash	20	1	17
	100	100	100

F-453410

FIGURE 20.—Disking followed by tractor logging creates the most favorable seedbed for germination of loblolly pine seed on most of the clear-cut area.

Disking is adapted to large timber or open stands, where the machinery is free to maneuver and where competing hardwoods are small (fig. 21). It cannot readily be done in dense stands of smaller timber. Thickets of sapling hardwoods also reduce its effect and form a mat over which the disk often rides without

cutting, especially if the disk is of the light-weight type. Disking is most effective if done in late summer before logging. The pine seedlings then get an even start with the hardwood sprouts, which do not arise in quantity until the following spring. However, logging cannot always be postponed until after late summer, disking after logging is unsatisfactory because stumps and slash interfere with the operation, and disking after seedfall buries much seed. Thus, some reduction in effectiveness must be accepted if year-round operations are carried out. This reduction usually is not serious, providing the seed supply is adequate. Tracts disked in spring and logged in summer, or disked in early winter and logged in spring, have regenerated satisfactorily in the Bigwoods, although not so abundantly as those disked and logged during the best period.

F-479363

FIGURE 21.—For best results, larger trees must be far enough apart to permit free movement of the tractor and disk.

Disking should be done progressively over the area to be treated. Small spots will inevitably be missed, but the cost of the operation will be substantially increased by attempts to cover 100 percent of the area. A stump or other heavy object attached behind the disk will help to hold it in the ground and to tear up the root mat, so that one passage of the machinery will break and uproot hardwoods up to 6 inches in diameter and expose mineral soil over the full width of the disk. Heavier disks are quite effective without the extra weight.

In northeastern North Carolina, a 40-horsepower tractor and a 2,200-pound diskharrow were used to treat 219 acres in 6 separate tracts at a direct cost of 2.66 man-hours and 1.14 tractor

hours per acre. In addition, repair costs were high because the disk was often damaged. Heavier disks now available are probably more economical in spite of higher initial cost. Other similar operations in the South have been carried out for 0.8 to 4.0 man-hours per acre and $1.20 to $5.00 per acre in other direct costs, mainly equipment operation (*107*).

Bulldozing is usually done in preparation for planting to convert stands of worthless upland hardwoods to pine. Where enough pine to serve as a seed source remains in the stand, however, bulldozing is also used to prepare the way for natural regeneration (fig. 22). Complete clearing is usually very costly, but the speed of the operation can often be increased by small changes in procedure. It may often be more efficient to leave larger trees to be girdled or poisoned in a follow-up operation (*83*). The bulldozing can then be confined to stem sizes not readily handled in other ways, and less area will be occupied by windrows and down trees. It is also advisable not to cut deeply into the soil, because the work is slowed down and because removal of surface soil will lower the site index for pine (*29*).

F-479338

FIGURE 22.—Bulldozing eradicates hardwoods and prepares an ideal seedbed for germination of pine seed.

Burning for seedbed preparation may be done either before or after logging but should always be done in late summer before seedfall (*15, 17*). Winter fires destroy most if not all seed on the ground, and an entire growing season before the next seedfall permits the growth of hardwood sprouts and herbaceous vegetation and the accumulation of litter.

The choice between before- or after-logging fires depends mainly on the time of logging. When logging is scheduled for the dormant season, a burn late the preceding summer will often result in maximum use of seed from the full stand. When logging is done in spring or summer, burning is best delayed until after logging because a fire before logging would again result in an advance growth of sprouts, and much reproduction would be destroyed in the logging operation. The latter objection to burning before spring or summer logging may not be important when a heavy seed crop follows the fire. Enough reproduction may be established so that the area would be satisfactorily stocked in spite of logging damage. In most years, however, the removal of a full stand would result in critical damage to established reproduction.

The logging operation may last through several seasons on large tracts but since these should always be divided by firelines for safety, the burning can readily be done at the most advantageous times in different parts of such tracts without additional expense.

The fire should be hot enough to kill the smaller hardwoods back to the ground and to consume logging slash and litter, so that mineral soil is exposed over most of the burned area (fig. 23 and tabulation p. 38). On the other hand, a hot fire may easily kill overstory pines because of their high initial temperature at that time of the year. Fire-killed trees are readily salvaged when the fire precedes logging, but a special operation would be needed if post-logging fire kills many trees of the seed source, and the seed supply might be seriously reduced. A series of small-scale trial fires after a rain will help in choosing the right conditions for burning.

Prelogging fires burn more uniformly because of continuous fuels, but logging slash remains. Post-logging fires tend to be more costly. Skidroads stop the spread, and repeated firing within the area is often needed for good results. The direct costs per acre of burning 412 acres in 12 separate fires over a period of 9 years in the Bigwoods Experimental Forest were as follows:

	Man-hours	*Tractor-plow-hours*
Firelines and other preparation	0.17	0.07
Burning	.57	.00
Mopup and patrol	.12	.00
Total	.86	.07

These costs are well within the range of those for prescribed burning throughout the southern pine region. A recent survey showed that prescribed burning in the South required 0.1 to 1.0 man-hours per acre and from 4 to 62 cents per acre for other direct costs, presumably equipment operation and materials (*107*).

Two other methods of using fire for the dual purpose of hardwood control and seedbed preparation are currently being tested at several locations in the Southeast. One consists of periodic winter fires during the rotation to keep the hardwoods small so that they may be more easily dealt with at the time of regeneration (*17*, *51*). The interval between fires is based on the growth

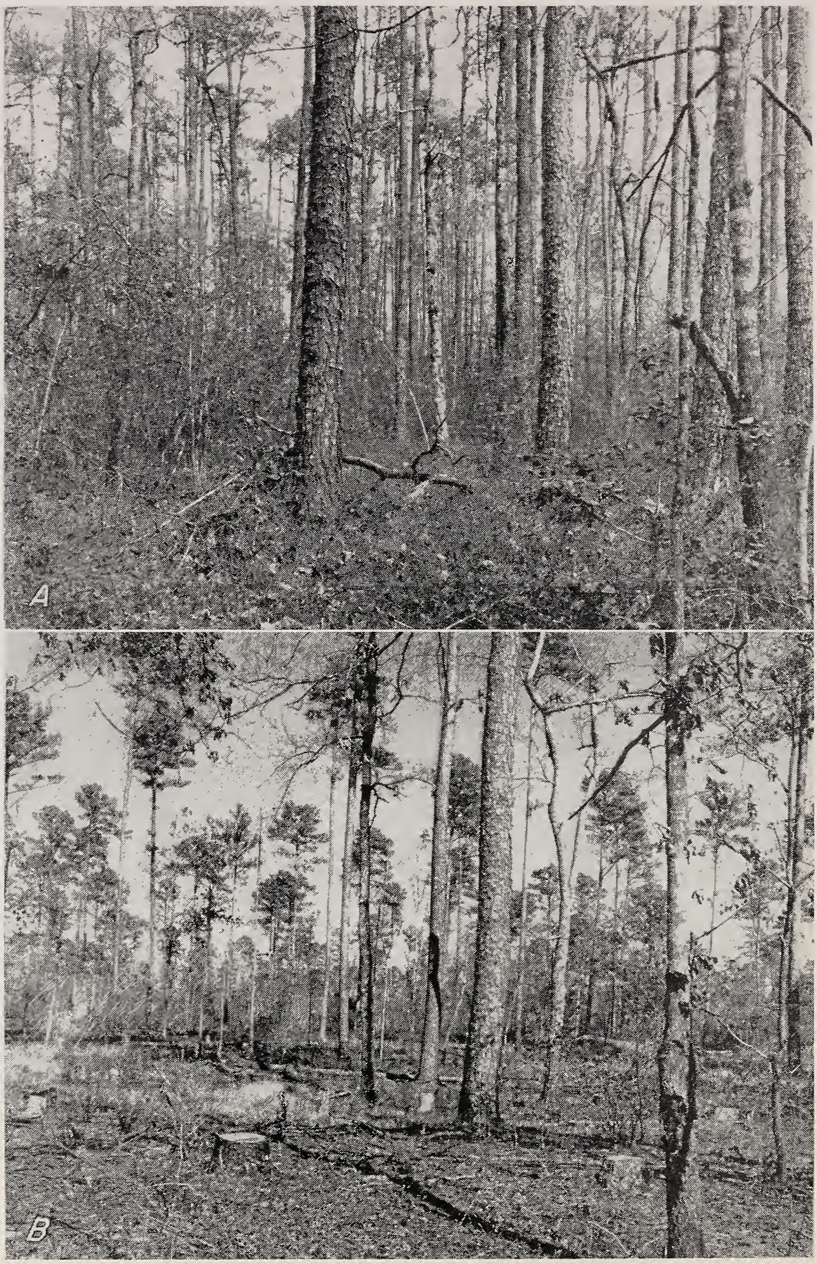

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FIGURE 23.—The effect of logging and fire: *A*, An undisturbed stand; *B*, the same scene after tractor logging followed by burning in late summer.

of the hardwoods; when the stems reach 1½ to 2 inches in diameter, the maximum size that can be killed back to the ground by a safe winter fire, the area is burned again. A final fire immediately before the harvest prepares the seedbed. This method has been in use in the Francis Marion National Forest in coastal South Carolina for several years and apparently is working satisfactorily (*79*).

The second method consists of an initial winter fire followed by several annual summer fires in advance of the harvest cut. In a study of the method on small plots in South Carolina, winter fires caused no reduction in sprouting vigor. Summer fires were much more effective; after 4 annual summer fires only one-half as many small hardwood stems and only one-third as much hardwood crown area was present as after 5 annual winter fires (*14*). A 30-acre pilot plant trial in the same locality has been at least as successful as the small-plot tests (*53*). This marked effect can be produced only by burning during summer, when sprouting vigor is at its lowest point of the year. In the Southeast that period extends from May to the middle of August (*100*). In avoiding damage to the stand during this period, the critical factor is the initial winter fire to reduce fuel so that subsequent summer fires will not injure the overstory pines when they are most sensitive to heat.

No difficulty was experienced in the South Carolina tests in getting good burns in the summer; favorable conditions occurred every year soon after the first of June (*53*). Repeated annual fires, winter or summer, apparently have no detrimental effect on the growth of the overstory. The small plots in the South Carolina study have been burned annually, in winter and in summer, for 8 years without affecting the radial growth of the overstory pines (*60*). Thus, these methods seem very promising for hardwood control and seedbed preparation and, with careful planning and execution to avoid damage to the pine stand and adjacent properties, should become useful additional tools in loblolly pine management.

Coordinating Seed Supply With Seedbed

Whether they are the result of tractor logging, more intensive scarification, or burning, favorable seedbed conditions deteriorate rapidly. Consequently, the seed required for the desired stocking of reproduction (*85*) must be supplied in the first year after logging or seedbed preparation.

Because cone crops can be predicted as much as a year in advance, harvest cutting can often be scheduled to take advantage of seed from the entire stand when a good seed crop is in prospect. Poorly stocked stands with heavy brush or hardwood competition can be most readily regenerated to well-stocked stands in that way (*66*). All cutting cannot be deferred until good seed years, however, because industry needs a continuous supply of wood, and much of it must come from harvest cuttings. But, with the advance information obtained by cone crop forecasts, better use can be made of the seed that does become available. Intensive seedbed preparation, such as burning or disking, will partly compensate

for a low seed supply and will give a reasonable assurance of satisfactory regeneration in mediocre seed years.

Although cone crop forecasts and intensive seedbed preparation are fully effective in many years, they can be considered only a partial solution to the problem of successful natural regeneration because of the occurrence of poor seed years. Even if the approach of a poor seed crop is known a year in advance, provision for sufficient seed is difficult because of the large number of seed trees required (table 3). And, because of the rapid deterioration of the seedbed, the seed production in subsequent years can seldom be relied upon to increase seedling stocking to a satisfactory level (*89*), even though it may be substantially greater because of the effect of release or more favorable cyclic factors. However, if the seed trees can be selected and released 3 to 5 years before the scheduled harvest, the greater seed production after release will coincide with fresh seedbed conditions, and the prospects of satisfactory regeneration will be greatly improved (*103*). The number of seed trees provided must always be enough for the poor seed years, which may occur at any time and cannot be predicted 3 years in advance (table 6).

The trees to be released should be chosen by the same criteria as unreleased seed trees, particularly with respect to crown class and fruitfulness. Large cone crops can be produced only if ample crown surface is available for cone-bearing; small-crowned trees cannot be expected to produce large crops, even though their response to release may be relatively great.

TABLE 6.—*Approximate minimum number of released seed trees needed per acre in a poor seed year to attain the specified stocking of reproduction in the first year after tractor logging*[1]

Desired reproduction (percent of milacres stocked)	Seed trees per acre when diameter at breast height in inches is—					
	10	12	14	16	18	20
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
40	20	8	4	3	3	3
60	44	16	8	5	3	3
75	80	29	14	8	5	4
90	--------	59	29	17	10	7

[1] Footnote to table 3, p. 32, also applies here.

If an average radius of 20 feet is cleared around each selected tree, releasing 35 trees per acre would mean clear cutting the rest of the stand. In this situation the stand has already been harvested, and when the released seed trees produce abundant seed 3 years later, the seedbed will have deteriorated. Thus, the expected benefits have been nullified. For this reason, it is not effective to release more than 15 seed trees per acre.

The minimum amount of release that will substantially increase cone production has not been determined. In the study previously described, the release to 2½ to 3 times the crown width caused

the response. Partial cuttings, resulting in less release for individual trees, have also brought about a response. As a general rule, an opening at least 10 feet wide on all sides of the crown of the selected tree is probably enough to increase cone production by a satisfactory amount. In addition, undesirable trees should be culled from the whole stand lest they transmit their faults to the reproduction.

In well-stocked stands the release cutting will yield an operable volume by most standards. The release of selected trees in a pole stand in southeastern Virginia produced 1.32 standard cords of pulpwood per tree released (*103*). The release of 4 seed trees per acre in 20-acre blocks in a 55-year-old stand produced 4 to 5 standard cords and 1,000 board-feet of logs per acre.

Although release has so far been tested only with scattered seed trees, strips could be similarly treated. Release of trees in strips would simplify both the release operation and the ultimate removal of the seed trees. However, the seed-tree requirement for the area as a whole would have to be fulfilled by the trees within the strips to achieve the desired stocking of reproduction. In managed stands the last thinning could probably be scheduled so that seed trees could be released at the same time.

The comparative importance of seed supply and seedbed conditions in obtaining satisfactory regeneration is shown by the results of compartment management studies that have been in progress in the Bigwoods Experimental Forest since 1946 (fig. 24). Twenty-two compartments averaging 35 acres in size were clear cut, leaving seed trees or strips, during the 7 years from 1946 to 1952. Undesirable hardwoods larger than 4.5 inches diameter at breast height were poisoned with 2,4,5–T in frills in the compartments that were disked before logging and in 5 of 11 compartments that were burned after logging. Hardwoods were not poisoned in the remaining burned compartments nor in those that received no seedbed preparation other than logging (table 7).

TABLE 7.—*Seedbed preparation and hardwood control measures in number of 35-acre compartments in the Bigwoods Experimental Forest, 1946–52*

First seed year	With hardwood control[1]		Without hardwood control	
	Burned after logging	Disked before logging	Burned after logging	Logging only
	Number	*Number*	*Number*	*Number*
1946			1	1
1947				1
1948	2	1		1
1949		1	1	
1950	1	1	1	1
1951	1	2		1
1952	1	1	3	
Total	5	6	6	5

[1] Hardwoods larger than 4.5 inches d.b.h. were poisoned with 2,4,5-T in frills after logging and seedbed treatments were completed.

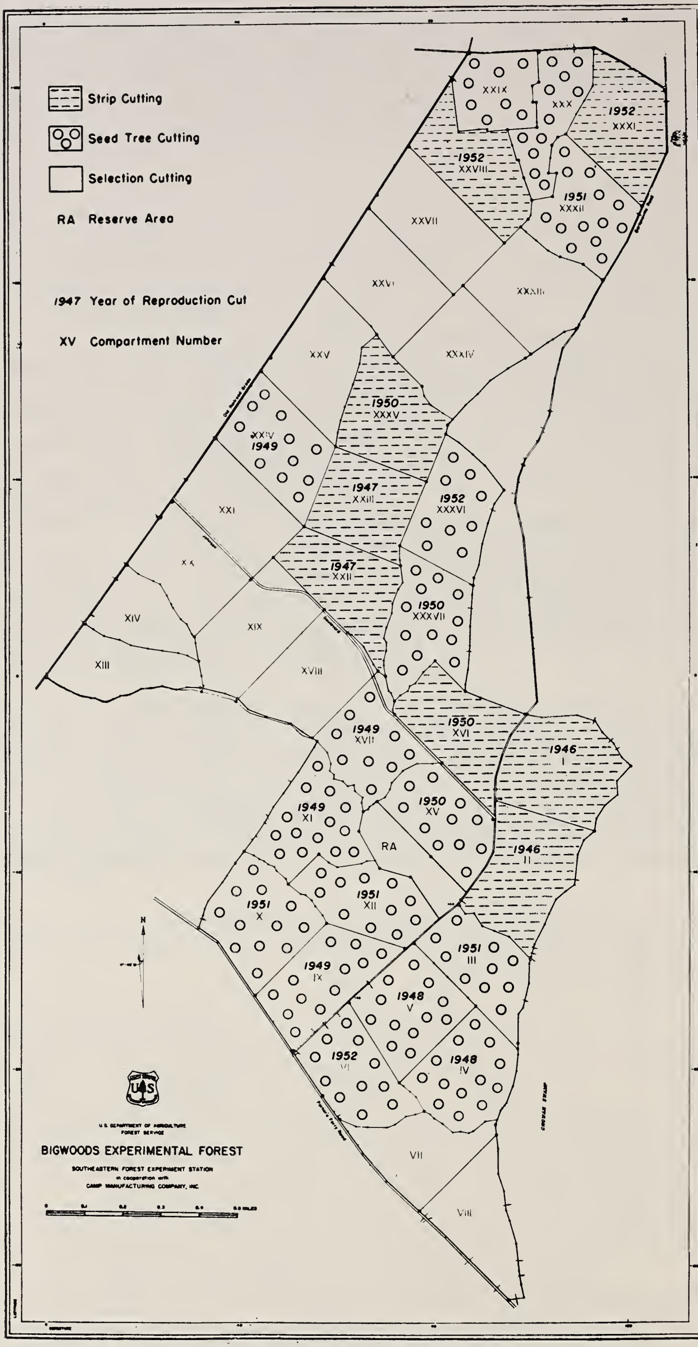

FIGURE 24.—The Bigwoods Experimental Forest—methods of harvest cutting used.

Seed supplies were estimated by means of sets of nine ¼-milacre seed traps in representative compartments. Seedling stands and stocking were arrived at by the counts on milacre plots in each compartment (table 8). Because of necessary preparatory work and the exigencies of logging operations, each kind of seed source (seed trees and strips) did not occur with each seedbed treatment in each year. Nevertheless, the data are extensive enough so that valid comparisons can be made.

With due allowance for these shortcomings, the data show that the *total number of seedlings* established was influenced by seedbed preparation as well as by seed supply. In the same year—and thus with roughly the same amount of seed—nearly 60 percent more seedlings were established in burned compartments and 80 percent more in disked compartments than in those that received no seedbed preparation other than logging. The effect of the seed supply was most clearly evident in the disked compartments, where the variation in number of seedlings established from year to year corresponded closely to the differences in amounts of seed. This effect was also evident after burning and after logging, although the relation was not so close as in the disked compartments.

The *stocking percentages* were also greater after seedbed preparation, particularly after disking. Milacre stocking was 1⅛ times as great in burned as in unburned compartments and 1⅓ times as great in disked as in undisked compartments. Stocking was satisfactory in 4 of the 5 compartments that received no seedbed preparation in addition to logging. This result must not be misconstrued to mean, however, that seedbed preparation is unnecessary. Ample supplies of seed will not be reflected in seedling establishment unless seedbed conditions are favorable. Satisfactory stocking was attained in the Bigwoods without additional seedbed preparation because logging created favorable seedbed conditions in a well-distributed pattern on a substantial percentage of the logged area.

Thus, both burning and disking considerably increased the number of seedlings established, but burning was distinctly less effective than disking in improving seedling stocking. Burning improved seedling stocking in good seed years but not at all in poor years. Disking, on the other hand, was as effective in the poor year of 1948 as in the good year of 1951. Of 6 compartments clear cut in the poor years of 1948 and 1949, 2 that had been disked became wellstocked with pine seedlings (fig. 25), but 3 burned and 1 unburned compartment reached satisfactory levels of stocking only after additional treatment in better seed years (table 8).

Fire is by its nature more variable than disking. Some fires burned well over the whole compartment, consuming all slash and litter and killing hardwoods up to 6 inches diameter at breast height (fig. 26). Others burned poorly and erratically. The reasons for the different behavior are not clear. Weather conditions are, of course, important but the type of vegetation also affects the fire. Burning before logging may produce more uniform results because of continuous, undisturbed fuel, but pure hardwood

TABLE 8.—*Seedling establishment in the first year after logging in relation to seed supply and seedbed preparation*

Year	Sound seeds per acre	Seedlings per acre				Milacres stocked[1]			
		Logged	Logged and burned	Disked and logged	Average	Logged	Logged and burned	Disked and logged	Average
	Thousands	*Number*	*Number*	*Number*	*Number*	*Percent*	*Percent*	*Percent*	*Percent*
1946	79-92	5,285	8,215	----	6,750	83	97	----	90
1947	98-99	10,103	----	----	10,103	88	----	----	88
1948	4	1,670	[2] 3,025	1,630	2,338	55	[2] 52	66	56
1949	16-19	----	890	2,230	1,560	----	43	76	60
1950	31-79	4,320	[2] 4,060	4,670	4,280	80	[2] 94	85	88
1951	140-150	1,560	4,670	[2] 5,490	4,300	43	72	[2] 83	70
1952	23-92	----	[3] 2,726	3,770	2,900	----	[3] 77	91	79
Average	----	4,590	3,465	3,880	----	70	74	81	----

[1] Goals of stocking were set according to kind of seedbed preparation and hardwood control and were as follows:
Logged—44 percent of milacres stocked.
Logged and burned, without hardwood control—44 percent of milacres stocked.
Logged and burned, with hardwood control—66 percent of milacres stocked.
Disked and logged—66 percent of milacres stocked.

[2] Average of 2 compartments.

[3] Average of 5 compartments.

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FIGURE 25.—Four-year-old reproduction that became established after the area was disked and logged in August of a very poor seed year. All seed came from eight seed trees per acre.

areas, such as result from "beetle kills," burn very poorly at all times.

Two of the three burned compartments were burned again in subsequent years to prepare a fresh seedbed. However, in spite of a marked increase in seed supply because of better seed years and the effect of release, satisfactory stocking was never attained in one, and in the other only after a third fire. The later fires burned well, killing hardwood sprouts and consuming herbaceous vegetation and litter on much of each compartment, so that seedbed conditions appeared favorable.

These results show that successful regeneration depends on seeding in the first year after logging. If seed supplies are inadequate in the first year and hardwoods gain dominance, the remedy must be drastic and will be expensive. Consistent success in regeneration of loblolly pine thus depends on careful planning to bring together adequate amounts of seed and favorable seedbed conditions.

Uneven-Aged Management

On the comparatively good sites of the Coastal Plain, silvical and silvicultural factors apparently present no serious obstacles to uneven-aged management of loblolly pine. Regeneration is readily obtained, and growth of seedlings is satisfactory in the open-

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FIGURE 26.—Three-year-old reproduction that became established after a severe fire in a mediocre seed year. Uncut strips 1 chain wide furnished the seed.

ings left by cutting mature trees (*94*). Thus, the choice between even-aged and uneven-aged management depends mainly on economic factors—the value returns or comparative yields over a rotation or longer period—a subject that lies beyond the scope of this discussion and merits much more space than could be given to it here. Loblolly pine is being grown in uneven-aged stands, notably at the Crossett Experimental Forest of the U. S. Forest Service in southeastern Arkansas, but also at several other locations, and value yield comparisons will become available in time.

From the silvicultural standpoint, the success of the selection system depends on prompt and plentiful reproduction in openings left by the removal of mature trees. The requirements of seed supply and seedbed conditions are the same as under even-aged management: plentiful seed must coincide with favorable seedbed conditions.

Ample supplies of seed can readily be assured by a cutting cycle of not more than 5 years (*66*). The increased seeding after the crown release of the preceding cutting then will be available for the fresh seedbed created by the current operation. The release accompanying a harvest cut under this system is enough to cause a substantial increase in seed production even in poor seed years (table 1).

Seedbed preparation presents somewhat greater difficulties. Normally, logging will cause considerable disturbance, which is

desirable in the new openings. At the same time, damage to established reproduction in other parts of the stand must be avoided. Disking may be possible in openings where regeneration has failed, but fire must be excluded from all-aged stands. However, disking unstocked openings on a practical scale over extensive areas presents operational difficulties that may limit its usefulness. The spots to be disked must be marked in some way and the operator led or directed to them; or the operator must be trained to recognize regeneration failures. Since openings in single-tree selection tend to be relatively small, the required tractor travel may result in critical damage to established reproduction. Consequently, it is likely that regeneration measures will be limited to the disturbance caused by logging and the effect of release on seeding, except in the few large openings that occasionally occur in all-aged management.

The release effect and logging disturbances are enough to assure regeneration in most cases. Twelve all-aged compartments in the Bigwoods had one harvest cut, up to 1950. They were not completely surveyed, but regeneration appears to be satisfactory in all but one. In general, it is less plentiful than in the even-aged compartments. Three of four compartments surveyed intensively would have 40 to 70 percent milacre stocking of free seedlings in openings if overtopping hardwoods were poisoned or girdled; the fourth had less than 40 percent stocking, which was considered unsatisfactory. Since these openings were made by the initial cut in these stands, the seed came from unreleased trees. In future cuts, which will be made at 5-year intervals, a much larger amount of seed will be available and reproduction in openings will very likely be ample in all the stands.

TREATMENT OF REPRODUCTION STANDS

Because prompt regeneration is a critical factor in profitable timber growing regardless of the silvicultural system used, the stocking of seedlings should be determined as soon as possible after seedling establishment. All seedlings that became established will not, however, survive and gain dominance over the competing hardwoods. Hence, the characteristics of potentially dominant seedlings must be known so that an owner can decide whether additional cultural measures are needed for raising the stocking to a desirable level.

Even-Aged Management

Growth and Development of Loblolly Pine Seedlings and Hardwoods After Clear Cutting

To judge the prospects of individual seedlings—which needs to be done to determine the success of even-aged regeneration—requires an estimate of future growth. That a relation exists between the appearance and vigor of tree seedlings is universally recognized. More detailed studies have shown that later height growth is related to a variety of current seedling characteristics,

such as height, and several expressions of stem form, crown, needle, and bud development *(104)*.[17]

The best indicator of the future height growth of a seedling is its past height growth. Not only is the relation between the two very close, but it is also easy to use in the field. The total height and number of branches are also good indicators of future growth, but the relations are influenced by environmental factors (fig. 27), which makes field use more difficult. When seedling height is taken into account, height growth is also highly correlated with stem form, stem foliation, needle length, and terminal bud length (fig. 28).

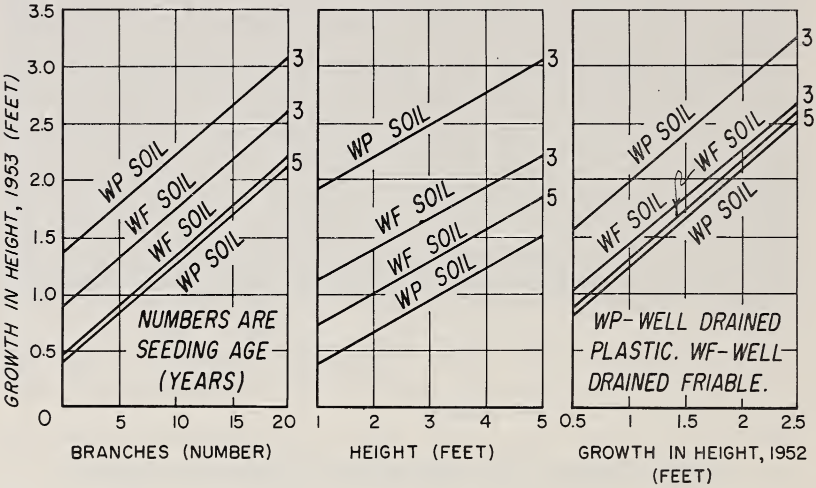

FIGURE 27.—The effect of soil and age on the relations of current seedling height growth to number of branches, initial height, and previous growth *(104)*.

Reliable estimates of the stocking of potentially dominant seedlings cannot be made until after the first growing season, because vegetational conditions are changing rapidly, and large numbers of seedlings are dying from causes other than competition. After the first year, mortality is much less and is apparently caused mainly by competition. In the Bigwoods, mortality rates were as follows *(105)*: 2-year-old seedlings (basis, 400), 1.1 percent; 3-year-old (basis, 400), 1.7; 4-year-old (basis, 300), 0.4; 5-year-old (basis, 300), 0.1. Heavy competition also seems to favor other causes of mortality. Of 443 4-year-old seedlings marked in 1947, 63 had died of natural causes 5 growing seasons later as indicated in the following tabulation. Of these, 55 had been overtopped by low competition, but competition was considered the cause of death in only 32 seedlings.

[17] Wahlenberg, W. G. Effect of overwood on survival and development of loblolly pine seedlings in southern Arkansas. 1946. (Unpublished report on file at the Southern Forest Expt. Sta., U.S. Forest Service.)

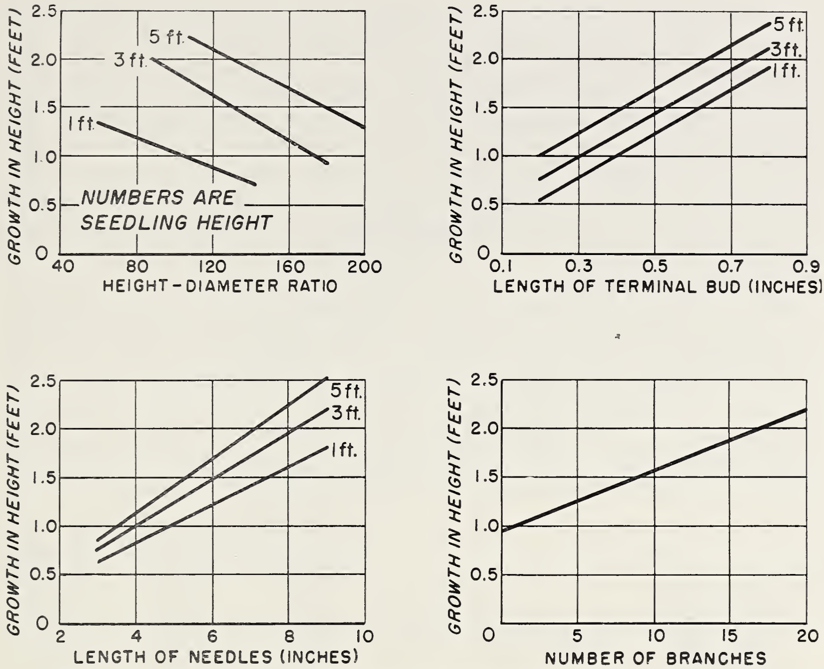

FIGURE 28.—The relation of one year's height growth to the specified seedling characteristics *(105)*.

Cause of death:	*Seedlings with leaders free*[1] *(number)*	*Seedlings overtopped*[2] *(number)*
Competition	2	32
Fusiform rust	0	2
Sawfly	5	13
Pine webworm	0	3
Rodents	0	2
Miscellaneous and unknown	1	3

[1] Basis: 179 seedlings.
[2] Basis: 264 seedlings.

Another factor that influences seedling growth to some extent is the activity of insects. Of the insects usually found attacking naturally regenerated loblolly pine seedlings in the South Atlantic Coastal Plain, the Nantucket pine moth (*Rhyacionia frustrana* (Comst.)) is probably the most common. Other insects, such as the red-headed pine sawfly (*Neodiprion lecontei* (Fitch)), the pales weevil (*Hylobius pales* (Hbst.)), and the pine webworm (*Tetralopha robustella* Zell.) occasionally become of concern locally. The pine moth, however, seems to be present in considerable numbers in seedling stands at all times.

A comparison of seedlings that had been attacked by the pine moth with uninfested seedlings showed that attack in only one year did not retard height growth *(104)*. However, when a series of attacks occurred in successive years, each year's attacks reduced height growth by 0.5 foot *(105)*.

The reliable evaluation of seedling prospects requires not only criteria of seedling growth but also some knowledge of the development of competing hardwoods. The composition of the future stand is in greatest doubt where the hardwoods are primarily sprout clumps of the same age as the pine seedlings. Where the hardwoods have not been disturbed, few pine seedlings become established; where hardwoods, including the roots, have been completely destroyed, seedling prospects are in little doubt. Thus the prediction of prospective dominance of seedlings is mainly a matter of comparing the behavior of the pine seedlings with hardwood sprout clumps.

Of the many hardwood species that compete with pine seedlings, the most numerous in the South Atlantic Coastal Plain probably are sweetgum, red maple, dogwood, waxmyrtle, and the red oaks (*Quercus* spp.) as a group. Sweetgum and red maple tend to be more numerous on heavy-textured, poorly drained soils; dogwood, waxmyrtle, and the red oaks are more numerous on well drained sandy loams and loamy sands. Sprout clumps of five hardwood species occurred as follows according to major soil groups (*105*):

Species:	*Relative frequency of sprout clumps*		
	Poorly drained plastic soil (percent)	*Well drained plastic soil (percent)*	*Well drained friable soil (percent)*
Sweetgum	41.5	39.0	26.0
Red maple	43.0	39.0	26.0
Red oaks	12.0	10.0	21.0
Dogwood	0.5	5.0	15.0
Waxmyrtle	3.0	7.0	12.0
	100.0	100.0	100.0

The rate of height growth of red oak sprout clumps was found to remain constant during the first 5 years, but in sweetgum and red maple it decreased from the initial rate (fig. 29). In sweetgum no lateral expansion occurred after the first year, indicating that one sprout quickly assumed dominance. Apparently no more lateral expansion took place until a treelike crown developed on the dominant sprout. In the other four species, crown width increased in proportion to total height, showing that they retained the sprout-clump form throughout the first 5 years.

Sweetgum, red maple, and the red oaks differed in their response to soils in the absence of burning, but after burning they all grew fastest on well drained friable soil, slower on well drained plastic soil, and slowest on the poorly drained plastic soil. Similar data are not available for waxmyrtle and dogwood.

The diameter of the stump and the season of cutting the parent stem also affect the rate of height growth of sprouts (*100*). Sprouts from winter cuttings grew as fast or faster than sprouts from summer cuttings; and sprouts from larger stumps grew faster than sprouts from smaller stumps.

However, the five species discussed above are but a small part of the total number of species of hardwood trees, shrubs, and vines that are found in clear-cut areas. The percentage of ground area covered by the crowns of these hardwoods has a direct bearing on the composition of the future stand since it is in some

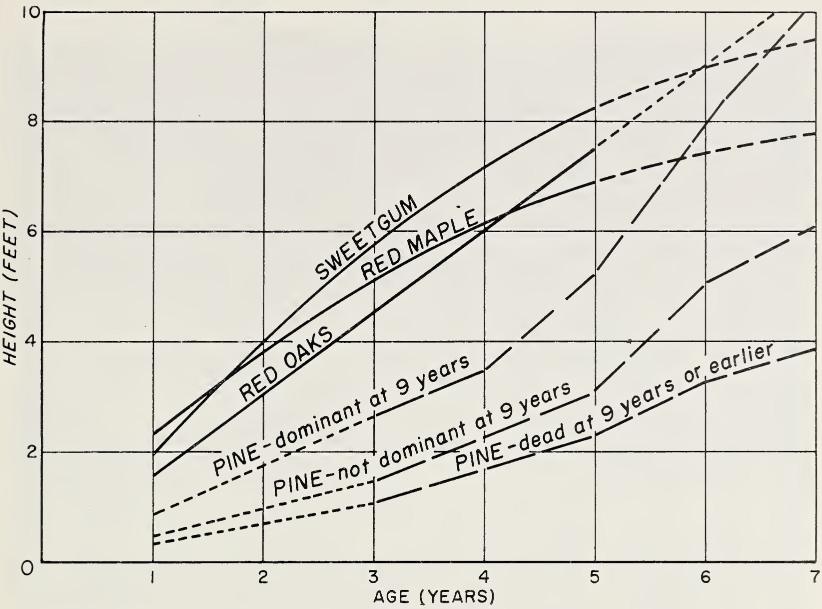

FIGURE 29.—The growth of hardwood sprout clumps and loblolly pine seedlings under average conditions *(105)*.

proportion unavailable to pine (fig. 30). On the other hand, pine seedlings are not entirely barred from the hardwood-cover area. Many small openings and the thin crowns of some species admit enough light for rapid growth of pine seedlings. In the South Atlantic Coastal Plain the area of hardwood cover increased rapidly in the first year after clear cutting, but by the third year the increase had slowed down to a low, constant rate (fig. 31). In the Georgia Piedmont the expansion of hardwood cover followed a similar course but at a slower rate, occupying only 35 percent of the ground area after 6 years (*8*).

Fire increased the growth of hardwood cover on two well drained soil groups but reduced it on poorly drained soils (fig. 31). The difference on the poorly drained soils was about twice as much as the difference on the well drained soils. The increased growth on the well drained soils was probably caused by the mineral nutrients and nitrogen released from the litter by burning. Aeration may have been retarded on the poorly drained plastic soils after the fire because these soils are more likely to puddle and pack when exposed.

Evaluation of Prospective Dominance

Because the growth rates of pine seedlings and hardwood sprouts vary widely and are influenced by many factors, the evaluation of pine seedling prospects must remain largely a matter of judgment.

A comparison of the height and past growth of pine seedlings and competing hardwood sprouts is an excellent basis for gaging

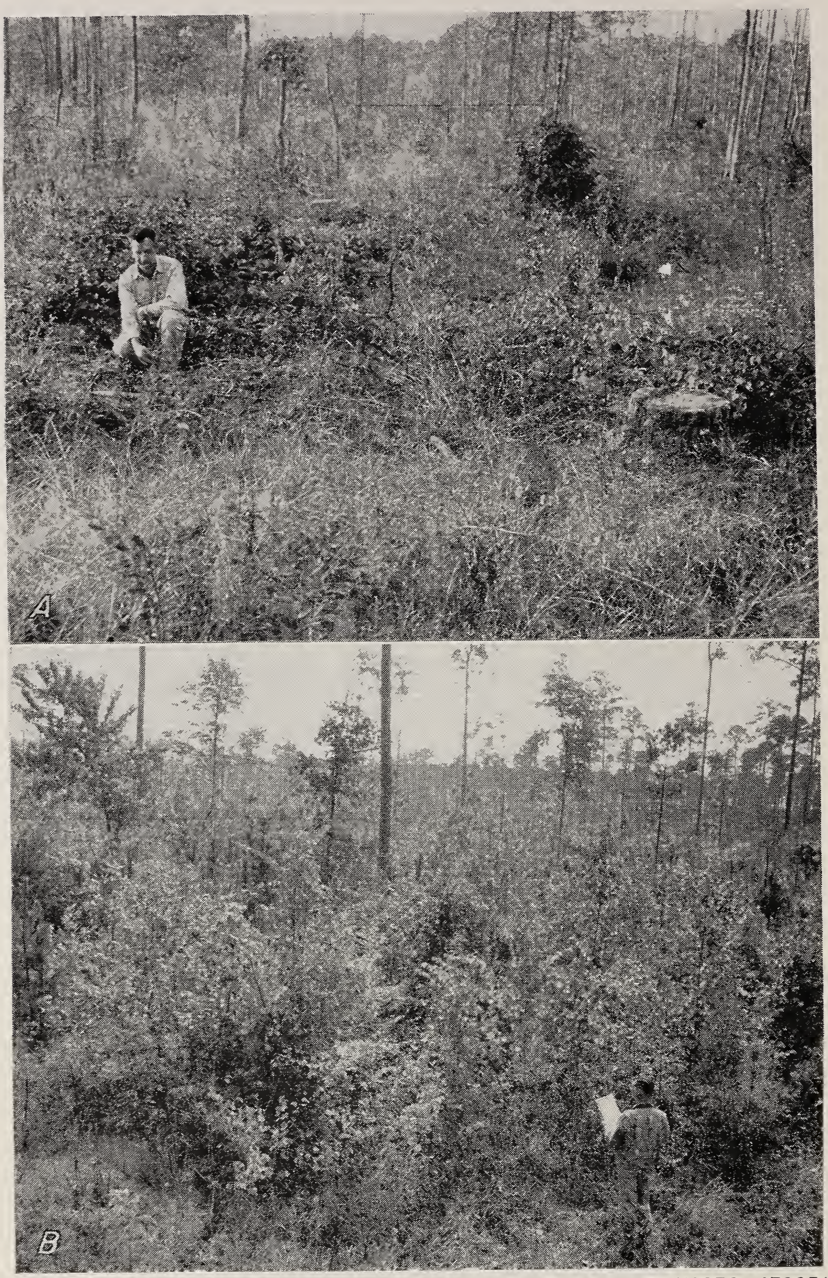

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Figure 30.—Vegetation develops rapidly in clear-cut areas: *A*, One year after logging; *B*, five years after logging.

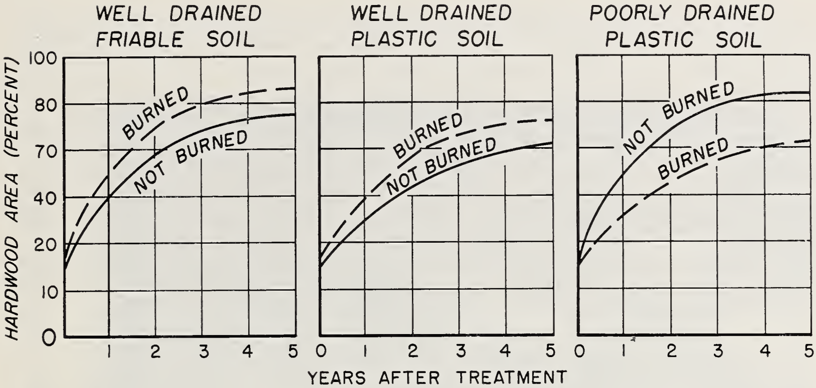

FIGURE 31.—The increase in area occupied by new hardwood growth in clear cuttings, by soil groups and surface treatments (*105*).

seedling prospects. The height growth of pine seedlings during the first 5 years tends to increase somewhat in each succeeding year. Wenger (*104*) found the following relation between the current year's growth (Y) and the previous year's growth (X), in feet:

$$Y = 0.35 + 1.02X.$$

The height growth of hardwood sprout clumps, on the other hand, tends to decrease during the same period from an initial high rate (fig. 29). The growth of the preceding year can be distinguished readily in most hardwood species by the color and texture of the bark and the ring of scars left by the scales of the terminal bud at the beginning of growth. Loblolly pine seedlings usually make several spurts of growth during the growing season, each shorter than the last and each marked by a whorl of branches (fig. 32).

A second, more objective basis for determining prospective dominance is freedom from overtopping in the third year or later (*8, 105*). In southeastern Virginia, 72 percent of seedlings with leaders free at 4 years were dominant at 9 years; but only 21 percent of seedlings overtopped at 4 years were dominant 5 years later. Of the predictions of both success and failure to attain dominance made on that basis, 74 percent were correct. That level of accuracy, already fairly good, could probably have been improved by taking into account the comparative height, position, and growth of the seedlings and competing sprout clumps.

The height of seedlings at a given age is also a fairly reliable basis for predicting seedling dominance. In the Virginia study, it was found that critical heights of 3-, 4-, and 5-year-old seedlings for dominance at 9 years were as follows: 3-year-old seedlings, 1.5 feet; 4-year-old, 2.0; 5-year-old, 4.0. Seedlings taller than these heights had a much better chance of becoming dominant than shorter seedlings. Of the predictions for both success and failure to attain dominance made on the basis of these heights, 72, 73, and 75 percent, respectively, were correct.

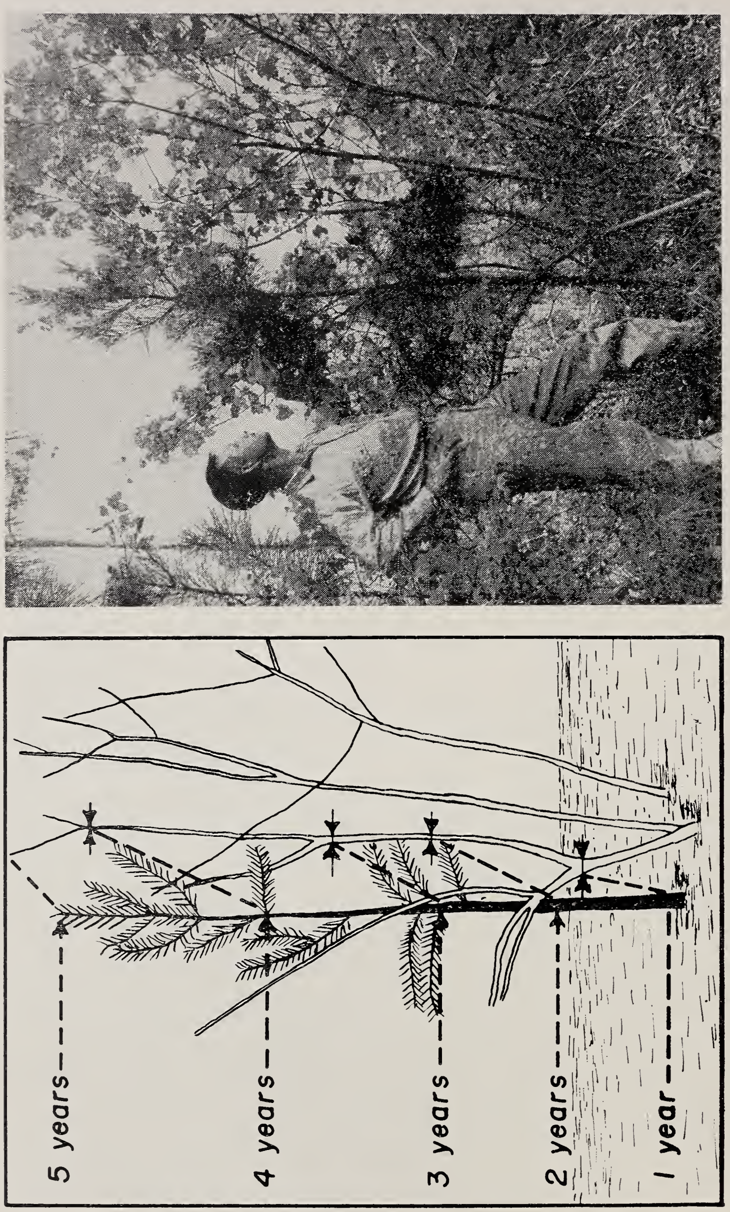

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FIGURE 32.—Height and position of a loblolly pine seedling and the clump of maple sprouts through which it grew. Notice particularly the increasing rate of height growth of the pine seedling (*105*).

The first two criteria of future dominance, comparative growth rates and free leaders in the third year of age or later are applicable on any upland site, since they are based on the relative positions of pine seedlings and hardwood competitors. The critical-height method, however, is applicable only on soils similar to those in the tract from which the data were obtained, because seedling height growth is influenced by soil characteristics. Those soils were sandy loams with friable sandy clay subsoils and ranged from very well drained to moderately drained. The method can probably be used, therefore, in many places in the South Atlantic Coastal Plain, where such soils are common.

Effect of Release

The removal of overtopping and competing hardwoods can considerably improve seedling prospects because loblolly pine seedlings respond quickly to release and usually grow rapidly thereafter. In a small-scale test in northeastern North Carolina a number of 2-year-old seedlings were completely liberated by poisoning overtopping white oak trees. All released seedlings responded to the treatment (fig. 33) and none died.[18] Heavily suppressed, low-vigor seedlings sometimes collapse when released, but they soon straighten and grow well (*105*).

An incomplete form of release involving cutting but no poisoning was tested in southeastern Virginia. Over 400 4-year-old seedlings were selected in a clear-cut area and paired according to total height and vigor. One of each pair was released by girdling large residual overtopping hardwoods and by cutting shrub and sprout growth for a distance from the seedling equal to one-half the height of the brush. Where seedlings had not been overtopped, the percentage that became dominant was increased but little by cutting the competing hardwoods (fig. 34). In contrast, release from overtopping hardwoods significantly increased the percentage dominant. Even with release, however, less than 60 percent of the overtopped seedlings became dominant. A somewhat higher percentage became dominant after a similar treatment in South Carolina (*80*).

The percentage of seedlings that became dominant was significantly smaller where they had been overtopped by large hardwood trees, even though these trees were girdled in the release treatment. Root competition probably was the cause, since the roots of the hardwoods were not killed by girdling and were sustained by the sprouts. Had the trees been poisoned instead of girdled, they probably would not have continued to affect the pine seedlings.

The response to release varied with soil moisture conditions, of which two distinct kinds existed in the study area. A significantly greater percentage of released seedlings became dominant on the drier than on the wetter part of the area. The hardwood stand was denser and sprouting more vigorous on the moist site. Consequently, the response of the pine seedlings to release was poorer than on the dry site, in spite of the more favorable soil moisture conditions.

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[18] Data on file at the Tidewater Forest Research Center, Franklin, Va.

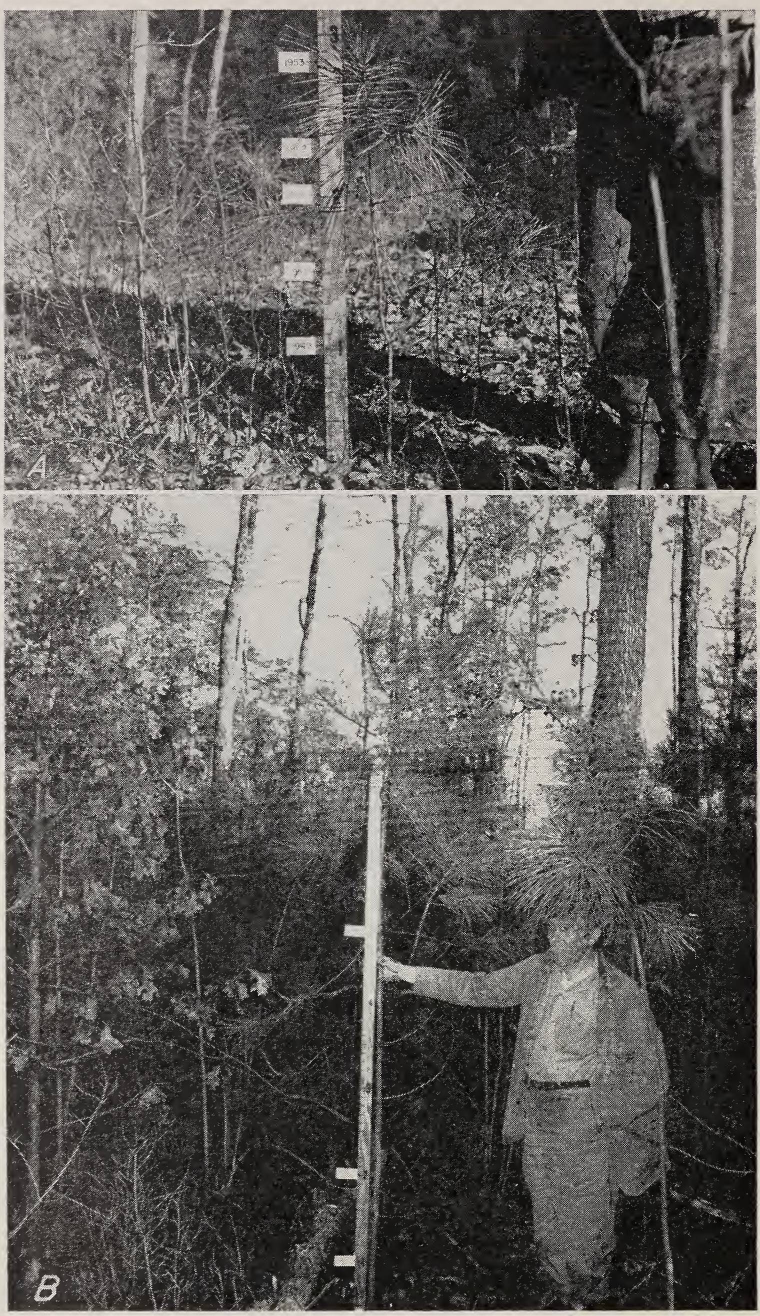

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FIGURE 33.—Height growth of released and unreleased seedlings: *A*, Unreleased, growth rate is decreasing; *B*, released by poisoning large, overtopping hardwood in background.

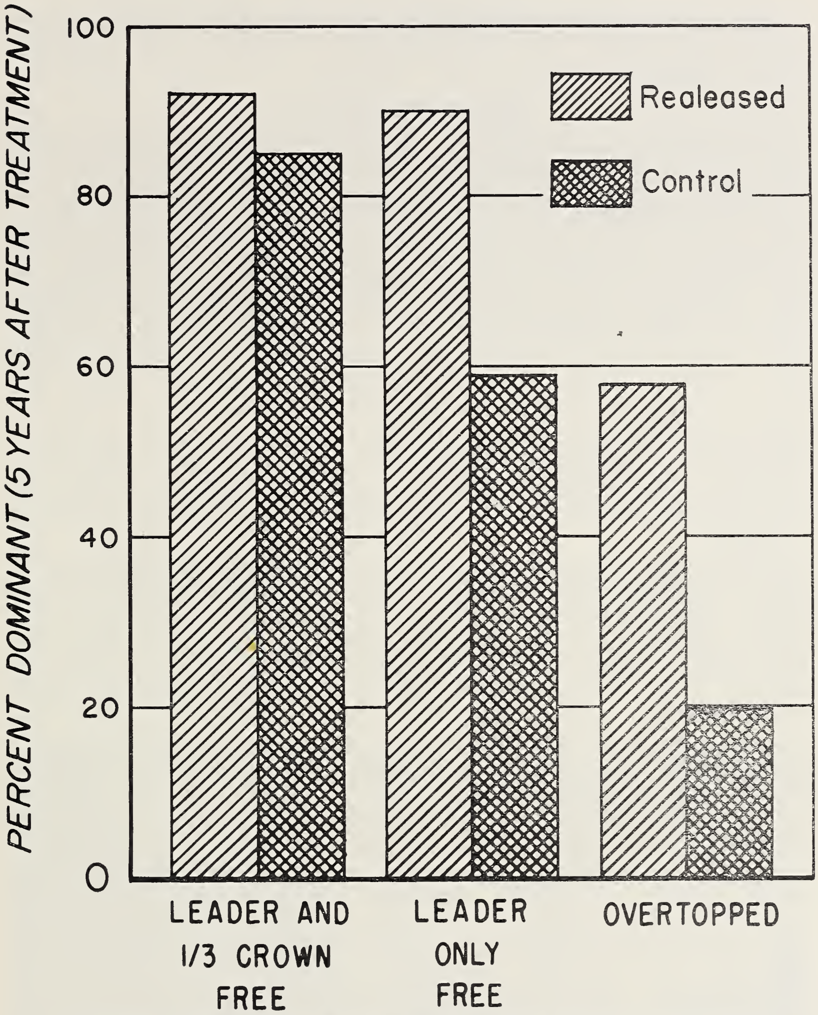

FIGURE 34.—Percentage of seedlings dominant 5 years after release, in relation to levels of low competition before release *(105)*.

No association was found between the frequency of attack by the Nantucket pine moth and the percentage of released or control seedlings that became dominant. Pine moth attack, therefore, did not prevent seedlings from becoming dominant if other factors were favorable. Frequency of attack was high, 69.5 percent of all seedlings having been attacked once or oftener during the 3-year period immediately after the release treatment.

A significantly higher percentage of released seedlings than control seedlings was attacked—74.5 percent compared to 63.9. This behavior agrees with that observed in other parts of the loblolly pine range (*39*). Release apparently exposes seedlings to more frequent attack.

These observations indicate that the pine moth usually is not a serious deterrent to the establishment of loblolly pine stands by natural regeneration.

Reproduction Survey

The decision to do release work depends not only on how much the stocking of free seedlings can be raised but also on the level of total stocking. When the stocking of free seedlings can be raised, say, from 30 to 50 percent, which is in the critical range for stand productivity, release would be worth while. But the profitability of release becomes questionable when the stocking of free seedlings is already fairly high, even though the stocking could be raised considerably. With low levels of total stocking, some owners may be satisfied to release whatever pine is present and accept a substantial percentage of desirable hardwoods. Others may want pure pine, even at the cost of drastic treatment, such as bulldozing. An overburden of weed hardwoods may, of course, dictate complete rehabilitation. Regardless of owner policy, however, sound planning requires a reliable estimate of both the total present stocking and the stocking of potentially dominant seedlings.

Estimates of reproduction are best made by the stocked-quadrat method because it reflects not only the number of seedlings present but also their distribution. In loblolly pine a convenient and satisfactory plot size is one milacre. Plots are located in some predetermined fashion so that all parts of the area in question are sampled. For some purposes a random distribution may be needed, but in practical work a systematic scheme is probably satisfactory in most sampling. Reproduction surveys in the Bigwoods Experimental Forest were made by means of 100 systematically located milacre plots per 35-acre tract.

The survey method can be modified in a number of ways to yield additional information for planning future work. One useful refinement is to record the kind of competition—residual hardwood trees or low brush—for plots stocked with a suppressed seedling. The tally would then show whether the pine seedlings need release from overhead competition or low competition or both.

If all plots are classified according to type of cover, whether seedlings are present or not, a rough estimate of the area under each type of cover can be obtained by applying the percentage of plots in each type to the whole area. If, in addition, the identity of individual plots is retained in the field record, the parts of the tract that need treatment can be located, since the direction of line and the plot interval are known.

If more precise estimates of types of hardwood cover are needed, they can be obtained by a line-intercept survey made while the observer moves along the cruise lines, or by a further modification of the plot survey. In the line-intercept method, the observer simply records the distance traveled through each type of cover along the line. The percentage of the total length of line in each type applied to the total area yields an estimate of the acreage in each cover type. Again, by maintaining the identity of

plot intervals, heavy concentrations of each cover type can be located.

Another method of obtaining more precise estimates of the area occupied by residual hardwood trees is to tally hardwood stems on a larger plot at some of the milacre plot locations. Surveys utilizing thirty $\frac{1}{10}$-acre plots per 35-acre tract in the Bigwoods have provided estimates of basal area of hardwoods accurate to within 10 percent of the actual basal area. An angle-gage or a wedge prism could also be used to estimate basal area (*9*, *37*). The basal area in hardwood stems multiplied by 1.4 yields an estimate of the percent of total area occupied by hardwood crowns, which is also an indication of the amount of growing space that would be made available to pine by removing the residual hardwoods (*65*).

Methods of Hardwood Control

The best way to get rid of unwanted hardwoods is to use them. That is not always possible, of course, but hardwood utilization is gradually improving. Eventually hardwood control may be limited to the destruction that occurs during seedbed preparation and to the elimination of cull trees.

Low-value hardwoods should not be destroyed unless pine seedlings or desirable hardwoods are present to benefit from release or are definitely in prospect because of intensive seedbed preparation and an adequate seed supply (fig. 35). When pine or desirable hardwood seedlings are lacking, no benefit can be expected from hardwood control.

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FIGURE 35.—Hardwood poisoned with Ammate to release a good catch of seedlings beneath its crown.

Felling is a sure and an immediately effective way to destroy overtopping hardwoods but has some disadvantages (*10*). It is likely to be more or less destructive to nearby pine seedlings, depending on the size of the hardwood crown. The fallen stems interfere with later operations, which might have serious consequences in fire control. In addition, felling takes more time than girdling or poisoning and is, therefore, more expensive.

Girdling overcomes most of these objections. It is cheaper than felling and the girdled trees remain standing for some time. However, sprouting usually occurs, some species die very slowly, and more care and supervision are needed for good results. Single-hack or frill girdles, double-hack or chip girdles, and notch girdles are all effective if done properly. A girdling machine, consisting of a rotary cutter on a flexible shaft driven by a gasoline motor carried on the operator's back, has recently become available. It is at least twice as fast as notch girdling (*108*).

Whatever the method, the inner bark and cambium must be completely severed around the entire circumference of the tree. Where bark and cambium have been enclosed by callus growth, the girdle should be made above or below the scar, or the enclosed bark must be completely chopped out.

Sprouting after girdling varies with species, season, size of tree, and probably with site quality (*10*). It is of little importance in trees larger than 11 or 12 inches in diameter at breast height. Many larger trees sprout very little, if at all, and are usually so widely spaced that what sprouting does occur affects only a negligible area.

Trees of smaller size sprout readily and are generally more numerous. Of the chemicals tested for killing them completely (*10*, *55*), many have been ineffective, costly, or dangerous to humans and livestock. None gained general acceptance until the synthetic plant hormones, 2,4–D and 2,4,5–T, were developed and the silvicidal properties of ammonium sulfamate were discovered. Methods of applying these chemicals to trees have been widely publicized[19] (*12*, *73*, and others) and will be described but briefly here. The most commonly used are as follows (*12*) :

Notches or cups.—One rounded tablespoonful of Ammate (about 1 ounce) placed in cups cut in the trunk near the base. The number of cups should be equal one-half the diameter at breast height of the tree in inches.

Frills.—Two gallons of 2,4,5–T (4 pounds acid equivalent per gallon) to 100 gallons of kerosene oil poured into a single-hack girdle at a convenient height on the tree.

Stumps.—A mixture of 1 gallon of 2,4,5–T to 20 gallons of oil sprayed to the point of runoff on the top and sides of freshly cut stumps; or Ammate placed on stump tops, 1 tablespoonful per 2 inches of stump diameter.

Cornell tool.—High concentrations of Ammate in water solution injected into the base of the tree.

Basal spray.—A mixture of 1 gallon of 2,4,5–T to 20 gallons of oil sprayed on the base of the tree in an encircling band, about

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[19] Peevy, F. A. How to kill blackjack oaks with Ammate. Southern Forest Expt. Sta., 3 pp. 1947. [Mimeographed.]

12 inches wide for stems under 2 inches diameter at breast height and 24 inches wide for larger stems.

Ammate in cups and 2,4,5–T in frills have been most widely used. Species vary in their susceptibility, which is reflected in the speed with which they die. Common species grouped in order of susceptibility to the specified method are as follows:

Ammate in cups (64)
- All oaks—easily killed.
- Sweetgum—easily killed.
- Sourwood—easily killed.
- Maple, hickory, holly—harder to kill.
- Beech—hardest to kill.

2,4,5–T in frills (13)
- White oaks—easily killed.
- Red oaks—somewhat harder to kill.
- Beech and hickory—not so easy to kill as oaks.
- Sweetgum and blackgum—slow to die.

Ammate kills quickly. Treated trees begin to show the effects in a matter of days and are dead in a few weeks. Trees treated with a water mixture of 2,4,5–T in frills react more slowly. Poisoned in the winter, they are not all dead till the following winter and frequently sprout below the frill before finally dying. As much as 2 years may sometimes be needed for the treatment to be fully effective. The most resistant species, sweetgum and blackgum, react slowly but usually deteriorate abruptly 9 to 12 months after treatment (*13*). A mixture of 2,4,5–T in oil applied in frills in early summer is much more effective with sweetgum, killing all stems within 12 months after application (*81*). Applied during the dormant season, it is little more effective than the water mixture.

Experimental trials have usually had satisfactory kills (*36*, *73*), but in practical applications results have often been less satisfactory, with poor top kill and much sprouting. Experimental applications can be made under optimum conditions, whereas large-scale, practical operations are often hampered by high labor turnover, unskilled workers, inadequate supervision, bad weather, and similar troubles. Good training and supervision are essential to the successful use of poisoning techniques.

Costs of girdling and poisoning vary widely, depending not only on the size and number of trees per acre but also on topography and other forest conditions, and on the experience and organization of the crew. Poisoning has been reported to cost \$3.30 to \$10.00 per acre, and girdling \$0.88 to \$8.00 per acre (*107*). In South Carolina, frilling with 2,4,5–T cost \$2.14, \$5.71, and \$8.56 per acre in three separate trials (*12*). Costs per average tree in cents have been as follows:

	Reported by Bull and Campbell (cents)	*Reported by Chaiken (12) (cents)*	*Bigwoods records (cents)*
Single-hack girdle	0.8—2.3	---	---
Double-hack girdle	1.4—5.5	4.8	---
Notch girdle	-------	---	6.0
Ammate in cups	1.7—6.9	7.1	7.3
2,4,5-T in frills	-------	3.0	5.3
2,4,5-T basal spray	-------	11.7	---
2,4,5-T stump spray	-------	8.8	---

The figures reported by Bull and Campbell[20] include all overhead costs; those reported by Chaiken and those recorded in the Bigwoods are direct costs only.

Except for basal and stump spraying, the major part of the cost is labor. Thus, a cost study of frilling with 2,4,5–T in South Carolina showed 71 percent of the total cost for labor, 9 percent for the chemical, and 20 percent for supervision, transportation, equipment, and overhead (*12*). Labor cost for girdling, ammating, and frilling can be estimated by means of the following formulas, in which *SD* is the sum of the diameters at breast height in inches, and *N* is the number of trees to be treated (fig. 36):

Notch girdling (*108*)—man-hours = 0.006005 (*SD*) — 0.010066 (*N*)
Machine girdling (*108*)—man-hours = 0.003641 (*SD*) — 0.008017 (*N*)
Ammate in cups (*58*)—man-hours = 0.009 (*SD*) — 0.005 (*N*)
Frilling with 2,4,5-T (Bigwoods data)—man-hours = 0.00584 (*SD*)

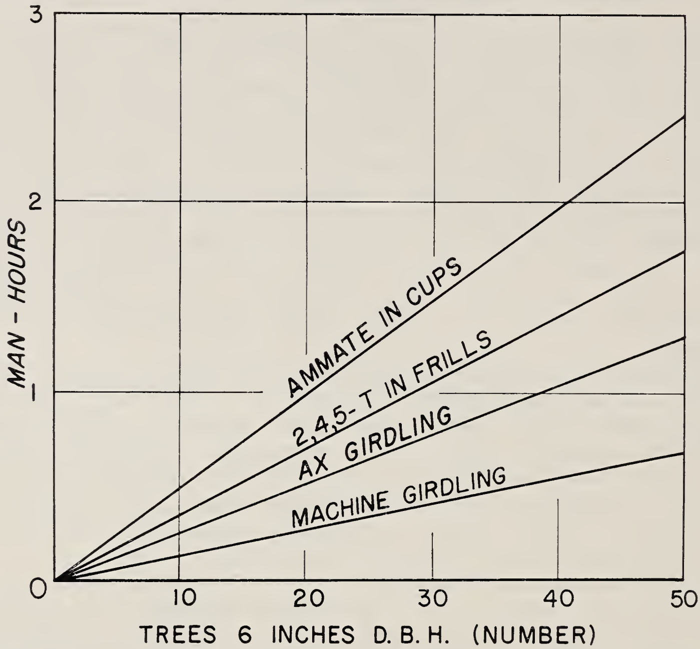

FIGURE 36.—Man-hour costs of four methods of hardwood control.

Low competition is best controlled by the standwise treatments used for seedbed preparation. However, sprouts always arise, and sometimes a cleaning is needed to raise the stocking of free seedlings to a satisfactory level. Results of cleaning trials have been erratic. In some trials one cleaning by simply cutting competing stems has been enough (*57*, *80*), but in others a second and third cleaning were needed. These variable results may be related to site quality through its effect on vigor of sprouting or to small size of seedlings when released.

[20] Bull, H., and Campbell, R. S. Recent research in poisoning southern weed hardwoods. Southern Forest Expt. Sta. 7 pp., 1949. [Mimeographed.]

The use of chemicals will considerably increase the chance of success, especially if the seedlings are small compared to the hardwoods. Chaiken (*12*) recommends a 3-percent mixture (acid by weight) of 2,4,5–T in oil to be applied to fresh stumps or as a basal spray. Although basal spraying is quite expensive for large stems because of the amount of solution needed, small stems probably can be treated economically. Excellent kill of trees averaging 1 inch diameter at breast height was obtained in South Carolina for less than one-half cent per tree (*12*).

How much space each seedling should be given is largely a matter of judgment. Assuming that the poisoned hardwoods will not sprout, the criteria of prospective dominance previously described could be used. Minimum release would consist of poisoning only the overtopping competitors. Treating all competitors within a distance related to their height would give more assurance of success. For example, in a release study in Virginia, all competitors were cut within a radius equal to one-half their height (*105*).

In order to keep down the cost of the job, no more seedlings should be released than are needed to obtain the desired stocking. Although experience in this kind of work is scanty, what has been done indicates that cleaning crews tend to do too much. Assuming that 50 percent milacre stocking is satisfactory, free seedlings should be spaced about 9 feet apart. At intervals of 9 feet a seedling should be released anywhere within a radius of 4½ feet only if a free seedling is not already present within the same radius. Always releasing the nearest overtopped seedling, or all overtopped seedlings encountered, will substantially increase the cost of the work. If much cleaning is to be done, thorough training of the crew will reduce costs.

The extent to which stocking of potentially dominant seedlings can be improved by release from competing hardwoods is indicated by the results of seedbed preparation and hardwood control in the Bigwoods Experimental Forest (table 9). The data were obtained from milacre surveys of the clear-cut compartments (fig. 37). With no seedbed preparation or hardwood control other than what resulted from tractor logging, 63 to 68 percent of the total stocking of seedlings was free of serious hardwood competition. When similar compartments were burned after logging, free seedlings amounted to 70 to 79 percent of the total stocking. The difference is largely due to hardwood stems under 2 inches diameter at breast height, which is normally the maximum size killed by after-logging fires. When larger hardwoods were poisoned in addition to burning after logging, 71 to 94 percent of the total stocking of seedlings was free to grow. In this situation the less uniform effects of fire, indicated by the greater range in the percentage of free seedlings, became evident with the elimination of the more or less constant cover of larger hardwoods (fig. 38).

Where seedbed preparation consisted of disking before logging rather than burning after logging, and larger hardwoods were also poisoned, 82 to 95 percent of the total stocking was free to grow. The higher percentage of free seedlings in disked compared to burned compartments reflects in part the greater effectiveness of disking in controlling small stems.

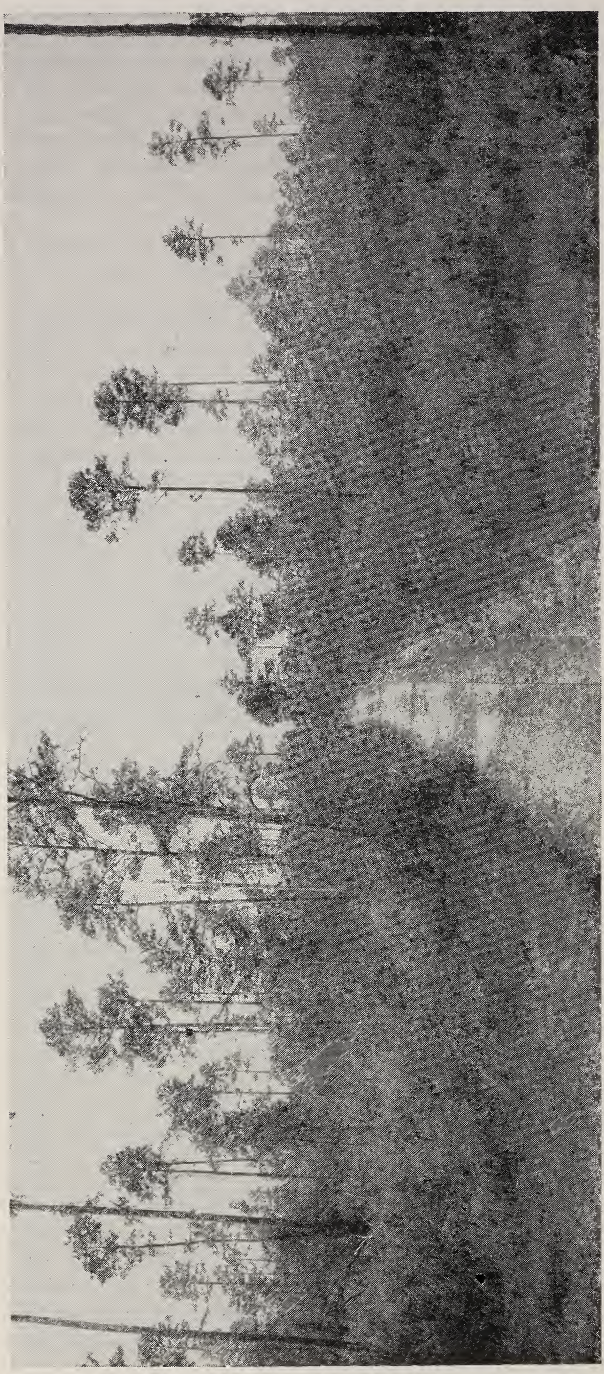

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FIGURE 37.—The tract to the left of the road was logged with crawler tractors but was given no other treatment. The tract to the right of the road was logged at the same time but was disked before logging, and the remaining hardwoods larger than 4.5 inches d.b.h. were poisoned after logging. The picture was taken 2 years after logging.

TABLE 9.—*Percent of total stocking free to grow, in relation to cultural treatments and age of cutting*

Years after harvest cut	No hardwood control		Hardwood control	
	Logged	Logged and burned	Logged and burned	Disked and logged
	Percent	*Percent*	*Percent*	*Percent*
1	65	79	88	93
2	65	79	94	95
3	64	74	78	94
4	63		71	82
5	68	70	80	

The need to impose some control on smaller, as well as larger stems, was shown by the results of a release study in southern Arkansas (*57*). The following intensities of treatment were tested: (1) Hardwoods 6 inches diameter at breast height and larger cut; (2) hardwoods 2 inches diameter at breast height and larger cut; and (3) hardwoods 5 feet tall and larger cut. Only those hardwoods were removed whose crowns reached within 2 feet of a seedling leader. The first treatment was inadequate, releasing less than 5 percent of the overtopped seedlings. The more intensive treatments increased the number of dominant seedlings by 571 and 695 per acre, respectively. Well-stocked stands of pine developed so rapidly after these 2 treatments that a thinning was made 10 years later. Although the volume was not

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FIGURE 38.—These hardwoods developed in the understory of a 95-year-old pine stand. They occupy a substantial percentage of the area and, unless removed, will effectively suppress pine seedlings established beneath their crowns.

operable, a thinning was made at the same time in the stand that developed after the lightest treatment. The thinnings more than paid for the cost of the two heavier treatments but fell short of paying for the lightest treatment by 15 cents per acre.

Therefore, release from hardwood competition can substantially increase the stocking of free-to-grow seedlings. Also, intensive seedbed preparation, such as disking before logging or a uniform fire after logging, can eliminate the need for release from low competition.

Uneven-Aged Management

Uneven-aged management depends on reproduction in the openings created by the harvest of mature trees. In Arkansas, the survival and growth of loblolly pine seedlings was found to be satisfactory in openings as small as 7.6 to 15.2 feet, although they were much poorer than in larger openings (*94*). The growth of understory hardwoods is undoubtedly also influenced by the size of the opening, but probably not to the same extent as the pine seedlings. However, seedling prospects can be evaluated in much the same way as in clear-cut areas, in spite of the somewhat different relation between the pine seedlings and their hardwood competitors. The comparison of past growth rates and overtopping in the third year or later should give as good indications of seedling prospects in openings in the selection stand as in clear cuttings.

The control of hardwoods is as important in uneven-aged as in even-aged management. The limitations on methods of seedbed preparation mean that more hardwoods, especially in the smaller sizes, will be present after the harvest cut than in clear-cut areas. Consequently, the cutover area should be treated a year or two after each cut to release pine reproduction in the new openings. Little need be added to the previous discussion of methods of hardwood control, for their effectiveness is not reduced by the proximity of larger pines.

SUMMARY

In terms of acreage, volume, and use, loblolly pine is the most important timber species in the South Atlantic Coastal Plain. The area in hardwood types is increasing throughout the territory, however, while that of the pine types is decreasing. Because of the area involved, limited supplies of planting stock, and the high cost of forest planting, the reversal of this trend can come about mainly by the use of natural seeding to reestablish the pine stands.

Loblolly pine stands readily become established in old fields or severely burned woodland. They are soon invaded by light-seeded, intolerant hardwoods and later by more tolerant species. If left undisturbed, they would inevitably be supplanted by the climax oak-hickory association. Cutting results in a variety of conditions, ranging from destruction of all vegetation and exposure of mineral soil to a complete lack of disturbance. The subsequent succession varies accordingly. The effects of fire are also variable and depend

on the age of the pine stand and on the intensity, frequency, and season of burning. Crown fires destroy the entire stand. Surface fires may be destructive in young stands and during the growing season but usually have little effect in the dormant season in older stands.

Consistent success in even-aged regeneration by natural seeding depends on careful planning to provide the required amount of seed in the first year after logging or seedbed preparation, when seedbed conditions are most favorable for germination and early survival. Tractor logging disturbs the litter and exposes mineral soil in a well-distributed pattern on about 50 percent of the clear-cut area. Disking before logging or burning in late summer before logging or within 1 year after logging increases the extent of favorable seedbed conditions to 80 to 85 percent of the area. Where an adequate loblolly pine seed source remains in stands of inferior hardwoods, bulldozing may also be used to prepare a seedbed for natural regeneration. However, these favorable seed-bed conditions deteriorate rapidly and by the third year after logging or seedbed preparation they have reverted to the undisturbed state. Approximately 3 to 4 times as much seed is needed in the second year and 11 times as much in the third year as in the first year after logging or seedbed preparation to establish a given number of seedlings. Sufficient seed must be supplied, therefore, in the first year.

With the seed-tree system, the number of seed trees needed varies with the seed year, the size and fruitfulness of available trees, the condition of the seedbed, and the stocking of reproduction desired. In mediocre and better seed years, 2 to 15 (depending on diameter at breast height) of the most fruitful dominant and codominant trees in the stand will usually produce enough seed for stand regeneration in tractor-logged or more intensively prepared areas. In poor seed years, the number of trees that are needed under most circumstances becomes prohibitively large. However, 3 years after release loblolly pine trees bear greatly increased cone crops and maintain greater production for at least 2 years more. Consequently, a reasonable number of trees selected and released 3 to 5 years before the scheduled harvest will usually produce sufficient seed for stand regeneration. Seedbed preparation in addition to seed-tree release will give greater assurance of success.

Whether or not seed trees should be removed after reproduction is established depends on the risk of fire. With a high risk, the seed trees may be needed to reestablish a second stand. If they are not to be harvested, the minimum number should be left, since they will contribute to the cost of establishing the new stand. If they are to be cut, enough should be left to provide an operable volume.

Seed may also be provided by uncut strips. These strips offer some advantages in marking, logging, and later removal but do not permit the degree of control of the seed supply that is possible in the selection of seed trees. The advantages of both methods may be partly realized by leaving seed trees in lines instead of scattered over the area.

In all-aged management, short cutting cycles of not more than 5 years usually result in ample seed because of the repeated release of some of the remaining trees. Seedbed preparation is largely limited to what occurs during logging, since openings are many, small, and scattered, and established reproduction must be protected.

The degree to which the desired stocking of reproduction has been attained can be determined in the third year or later by the stocked-quadrat method. A comparison of the position and growth rates of pine seedlings and their hardwood competitors, and freedom from overtopping will indicate which seedlings are likely to surpass their competitors and become dominant. Reproduction surveys will also show the amount of release needed.

The removal of hardwood competition may often increase the stocking of potentially dominant seedlings from unproductive to satisfactory levels. Unmerchantable, overtopping hardwood trees should be killed by poisoning or girdling. Cleanings can be made by cutting, but best results are obtained by poisoning stumps or by basal spraying stems.

Hardwood control is also frequently necessary in all-aged management. The methods used in even-aged management are also effective in the openings where seedlings have become established in selection stands.

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